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ENVIRONMENTAL MONITORING AND DISPOSAL OF RADIOACTIVE WASTES FROM U.S. NAVAL NUCLEAR-POWERED SHIPS AND THEIR SUPPORT FACILITIES

NAVAL NUCLEAR PROPULSION PROGRAM
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ENVIRONMENTAL MONITORING AND DISPOSAL OF RADIOACTIVE WASTES FROM U.S. NAVAL NUCLEAR-POWERED SHIPS AND THEIR SUPPORT FACILITIES 2000

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ABSTRACT

This report assesses the environmental effect of disposal of radioactive wastes originating from U.S. naval nuclear propulsion plants and their support facilities. The total long-lived gamma radioactivity in liquids discharged to all ports and harbors from all naval nuclear-powered ships and supporting tenders, naval bases, and shipyards was less than 0.002 curie in 2000. To put this small quantity of radioactivity into perspective, it is less than the quantity of naturally occurring radioactivity in the volume of saline harbor water occupied by a single submarine. This report confirms that procedures used by the Navy to control releases of radioactivity from U.S. naval nuclear-powered ships and their support facilities are effective in protecting the environment and the health and safety of the general public. These procedures have ensured that no member of the general public has received measurable radiation exposure as a result of operations of the Naval Nuclear Propulsion Program.

The successful radiological deactivation and closures of Ingalls Shipbuilding radiological facilities in 1982 and of the Charleston and Mare Island Naval Shipyards in 1996 demonstrate that the stringent control over radioactivity exercised by the Naval Nuclear Propulsion Program from its inception has been successful in preventing radiological contamination of the environment and in avoiding expensive radiological liabilities at shipyards.

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SUMMARY

The radioactivity in materials discussed in this report originates in the pressurized water reactors of U.S. naval nuclear-powered ships. As of the end of 2000, the U.S. Navy had 74 nuclear-powered submarines, 9 nuclear-powered surface ships, and 2 moored training ships in operation. Facilities involved in construction, maintenance, overhaul, and refueling of these nuclear propulsion plants include six shipyards, two tenders, and five naval bases. This report describes disposal of radioactive liquid, transportation and disposal of solid wastes, and monitoring of the environment to determine the effect of radioactive releases, and updates reports on this subject issued by the Navy in references 1 through 5 (references are listed on page 33). This report concludes that radioactivity associated with U.S. naval nuclear-powered ships has had no discernible effect on the quality of the environment. A summary of the radiological information supporting this conclusion follows:

From the start of the Naval Nuclear Propulsion Program, the policy of the U.S. Navy has been to reduce to the minimum practicable the amounts of radioactivity released into harbors. Since 1971, the total long-lived gamma radioactivity released each year within 12 miles from shore from all U.S. naval nuclear-powered ships and their support facilities has been less than 0.002 curie; this includes all harbors, both U.S. and foreign, entered by these ships.

As a measure of the significance of these data, if one person were able to drink the entire amount of radioactivity discharged into any harbor in any of the last 30 years, that person would not exceed the annual radiation exposure permitted for an individual worker by the Nuclear Regulatory Commission.

Environmental monitoring is conducted by the U.S. Navy in U.S. and foreign harbors frequented by U.S. naval nuclear-powered ships. This monitoring consists of analyzing harbor sediment, water, and marine life samples for radioactivity associated with naval nuclear propulsion plants; radiation monitoring around the perimeter of support facilities; and effluent monitoring. Environmental samples from each of these harbors are also checked at least annually by a Department of Energy laboratory to ensure analytical procedures are correct and standardized.

Independent environmental monitoring has been conducted by the Environmental Protection Agency in U.S. harbors during the past several decades. The results of these extensive, detailed surveys have been consistent with Navy results. These surveys have again confirmed that U.S. naval nuclear-powered ships and support facilities have had no discernible effect on the radioactivity of the environment.

RADIOACTIVE LIQUID PROCESSING AND CONTROL

Policy and Procedures Minimizing Release of Radioactivity in Harbors

The policy of the U.S. Navy is to reduce to the minimum practicable the amounts of radioactivity released to the environment, particularly within 12 miles of shore. This policy is consistent with applicable recommendations issued by the Federal Radiation Council (incorporated into the Environmental Protection Agency in 1970), U.S. Nuclear Regulatory Commission, National Council on Radiation Protection and Measurements, International Commission on Radiological Protection, International Atomic Energy Agency, and National Academy of Sciences--National Research Council (references 6 through 15). Keeping releases small minimizes the radioactivity available to build up in the environment or to concentrate in marine life. To implement this policy of minimizing releases, the Navy has issued standard instructions defining radioactive release limits and procedures to be used by U.S. naval nuclear-powered ships and their support facilities.

Source of Radioactivity

In the shipboard reactors, pressurized water circulating through the reactor core picks up the heat of nuclear reaction. The reactor cooling water circulates through a closed piping system to heat exchangers, which transfer the heat to water in a secondary steam system isolated from the primary cooling water. The steam is then used as the source of power for the propulsion plant, as well as for auxiliary machinery. When reactor coolant water expands as a result of being heated to operating temperature, the coolant passes through an ion exchange resin bed for purification before being transferred to holding tanks.

The principal source of radioactivity in liquid effluents is trace amounts of corrosion and wear products from reactor plant metal surfaces in contact with reactor cooling water. Radionuclides with half-lives of approximately one day or greater in these corrosion and wear products include tungsten 187, chromium 51, hafnium 181, iron 59, iron 55, nickel 63, niobium 95, zirconium 95, tantalum 182, manganese 54, cobalt 58, and cobalt 60. The most predominant of these is cobalt 60, which has a half-life of 5.3 years. Cobalt 60 also has the most restrictive concentration limit in water (as listed by organizations that set radiological standards in references 6 and 7 for these corrosion and wear radionuclides). Therefore, cobalt 60 is the primary radionuclide of interest for naval nuclear propulsion plants.

Radioactivity Removal From Liquid at Shore Facilities

Radioactive liquids at shore facilities are collected in stainless steel tanks and pumped through a processing system to remove most of the radioactivity (exclusive of tritium) prior to collection in a clean tank for potential reuse. Even after processing to approximately 10^{-8} microcuries of gamma radioactivity per milliliter, reactor coolant is not

discharged to surrounding waters. Figure 1 shows a simplified block diagram of the liquid processing system, which consists of particulate filters, activated carbon bed filters, mixed hydrogen hydroxyl resin, and colloid removal resin beds. This type of processing system has been developed and used successfully to produce high-quality water containing very low radioactivity levels. This high-quality processed water is either returned to nuclear-powered ships or evaporated.

Liquid Releases in Harbors

The total amount of long-lived gamma radioactivity released into harbors and seas within 12 miles of shore has been less than 0.002 curie during each of the last 30 years. This total is for releases from U.S. naval nuclear-powered ships and from the supporting shipyards, tenders, and submarine bases, and at operating bases and home ports in the U.S. and overseas and all other U.S. and foreign ports that were visited by naval nuclear-powered ships.

To put this small quantity of radioactivity into perspective, it is less than the quantity of naturally occurring radioactivity (reference 16) in the volume of saline harbor water occupied by a single nuclear-powered submarine.

Short-Lived Radionuclides

Reactor coolant also contains short-lived radionuclides with half-lives of seconds to hours. Their highest concentrations in reactor coolant are from nitrogen 16 (7 second half-life), nitrogen 13 (10 minute half-life), fluorine 18 (1.8 hour half-life), argon 41 (1.8 hour half-life) and manganese 56 (2.6 hour half-life). For the longest-lived of these, about one day after discharge from an operating reactor, the concentration is reduced to one-thousandth of the initial concentration, and in about two days the concentration is reduced to one-millionth. Further, essentially all of the water is held onboard ship or transferred to shore facilities for processing and potential reuse and not discharged. Consequently, these short-lived radionuclides are not important for liquid release considerations.

Fission Product Radionuclides

Fission products produced from fuel in the reactor, including iodine and the fission gases krypton and xenon, are retained within the fuel elements. However, trace quantities of naturally occurring uranium impurities in reactor structural materials release small amounts of fission products to reactor coolant. The concentrations of fission products and the volumes of reactor coolant released are so low, however, that the total radioactivity attributed to long-lived fission product radionuclides comprises only a small fraction of the total long-lived gamma radioactivity releases discussed elsewhere in this report.

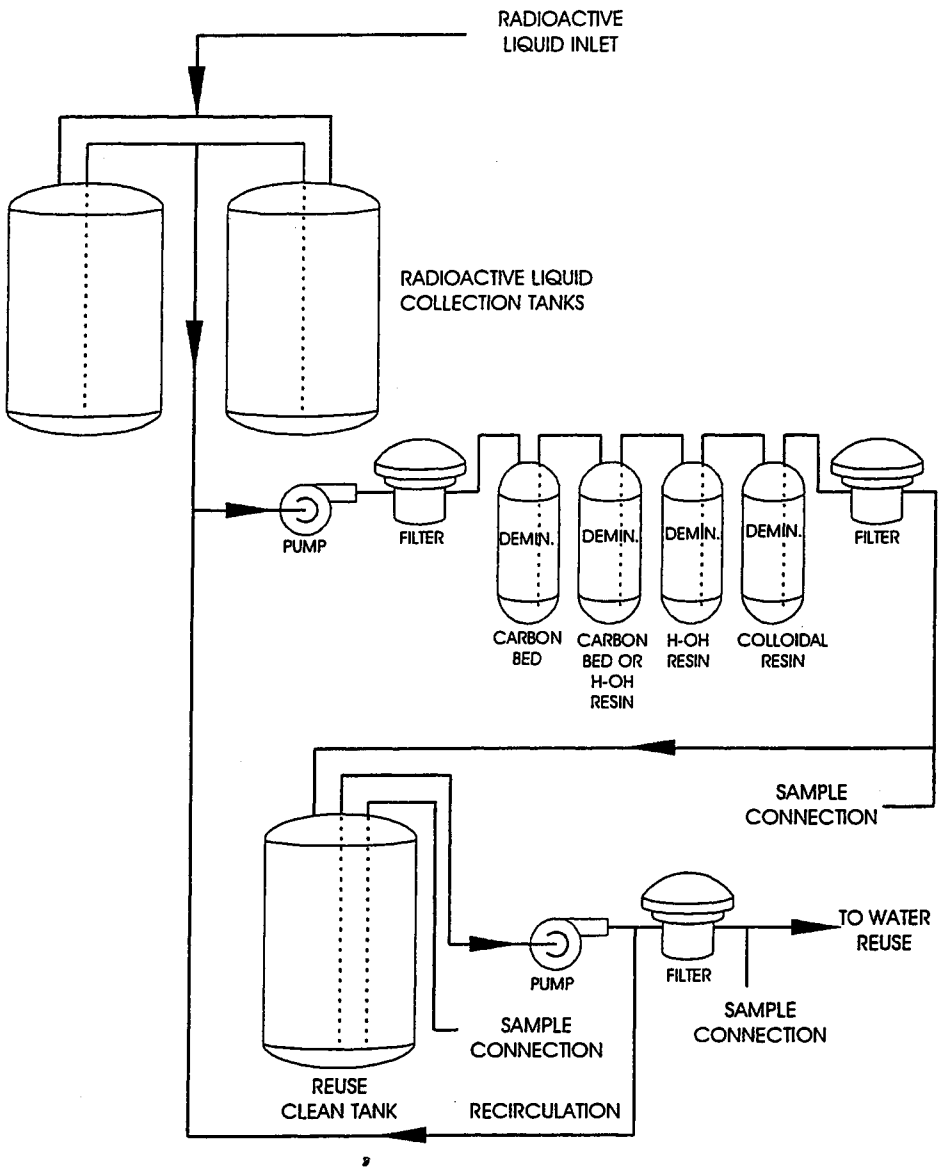


Figure 1
Simplified Diagram of Radioactive Liquid Processing System

Tritium

Tritium is a radioactive isotope of hydrogen. Trace amounts of tritium are formed in reactor coolant systems when neutrons interact with deuterium (a non-radioactive isotope of hydrogen) which is naturally present in about 0.015 percent of seawater. Although tritium does have a half-life of 12 years, the radiation it produces is of such low energy as to be environmentally insignificant. In fact, the safety guidelines issued by the International Commission on Radiological Protection, the National Council on Radiation Protection and Measurements, the U.S. Nuclear Regulatory Commission, and other standard-setting agencies permit the presence of 100 times as much tritium as cobalt 60. The tritium produced by naval nuclear reactors is in the oxide form, chemically indistinguishable from water. Therefore, unlike other radionuclides, it neither concentrates significantly in marine life nor collects on sediment.

Tritium occurs naturally in the environment, generated by cosmic radiation in the upper atmosphere. According to reference 17, cosmic radiation produces about 4 million curies of tritium per year. This means that there is a global inventory of about 70 million curies of tritium at any given time, about 45 million curies of which are in the oceans (reference 18). In comparison, the amount of tritium released each year from all U.S. naval nuclear-powered ships and their supporting tenders, bases, and shipyards has always been less than 200 curies—and virtually all of that was released into the ocean more than 12 miles from shore. This amount is less than the tritium released annually to the environment by a single commercial nuclear power station (reference 19). Further, the amount of tritium in water released within 12 miles of shore by U.S. naval nuclear-powered ships and their support facilities is less than one curie.

Because the amount of tritium occurring naturally in the environment is so large, the amount produced by U.S. naval reactors is too small to have any measurable effect on the environment. Therefore, tritium has not been combined with data on other radionuclides in this report.

Carbon 14

Carbon 14 is also formed in small quantities in reactor coolant systems as a result of neutron interactions with nitrogen and oxygen. Carbon 14 decays with a half-life of 5,730 years. Only low energy beta radiation is emitted during decay. As a result, the radioactivity concentration guides for carbon 14 in its chemical form in air issued by the International Commission on Radiological Protection, the National Council on Radiation Protection and Measurements, the U.S. Nuclear Regulatory Commission, and other standard-setting organizations are 60 times higher than for cobalt 60.

Carbon 14 occurs naturally in the environment. It is generated from cosmic radiation interactions with nitrogen and oxygen in the upper atmosphere and oxidized to form carbon dioxide. Carbon 14 is chemically indistinguishable from other isotopes of

carbon. The carbon dioxide diffuses and convects throughout the atmosphere and enters the earth's carbon cycle. Reference 20 states that the earth's natural carbon 14 inventory is estimated to be about 250 million curies, of which approximately 95 percent resides in the oceans. The total amount of carbon 14 released annually from the operation of all U.S. naval nuclear-powered ships and their supporting tenders, bases, and shipyards has been less than 100 curies, which is far less than the natural carbon 14 production rate of 40,000 curies per year (reference 20). Since the inventory of naturally occurring carbon 14 is so large, it is extremely unlikely that releases from naval nuclear reactors could result in a measurable change in the background concentration of carbon 14.

Liquid Releases at Sea

Radioactive liquids incidental to the operation of the nuclear propulsion plants are released at sea under strict controls. These ocean releases are consistent with recommendations the Council on Environmental Quality made in 1970 to the President in reference 21, and consistent with the Marine Protection, Research, and Sanctuaries Act, reference 22. Procedures and limits for ocean releases have been consistent with recommendations made by the National Academy of Sciences--National Research Council in reference 10 and by the International Atomic Energy Agency in reference 11. Navy releases have contained much less radioactivity than the recommendations of these reports. Since 1973, the total long-lived gamma radioactivity released more than 12 miles from shore by U.S. naval nuclear-powered ships and supporting tenders has been less than or equal to 0.4 curie per year. Releases occur at different times of the year in the open sea at long distances from land in small amounts, and under rapid dispersal conditions due to wave action. This 0.4 curie is less than the naturally occurring radioactivity (reference 16) in a cube of sea water approximately 100 yards on a side.

Loss of USS THRESHER and USS SCORPION

Two U.S. naval nuclear-powered submarines have been lost at sea in the Atlantic Ocean. The submarine THRESHER sank 10 April 1963, 200 miles southeast of Maine in water 8,500 feet deep. The submarine SCORPION sank on 22 May 1968, 400 miles southwest of the Azores in more than 10,000 feet of water. The reactors used in all U.S. naval submarines and surface ships are designed to minimize potential hazards to the environment even under the most severe casualty conditions, such as the actual sinking of the ship. First, the reactor core is designed so that it is physically impossible for it to explode like a bomb. Second, the reactor fuel elements are made of materials that are extremely corrosion resistant, even in seawater. The reactor core could remain submerged in seawater for centuries without releases of fission products while the radioactivity decays, since the protective cladding on the fuel elements corrodes only a few millionths of an inch per year. Thus, in the event of a serious accident where the reactor is completely submerged in seawater, the fuel elements will remain intact for an indefinite period of time, and the radioactive material contained in these fuel elements should not be released. The

maximum rate of release and dispersal of the radioactivity in the ocean, even if the protective cladding on the fuel were destroyed, would be so low as to be insignificant.

Radioactive material could be released from this type of reactor only if the fuel elements were actually to melt and, in addition, the high-strength, all-welded reactor system boundary were to rupture. The reactor's many protective devices and inherent self-regulating features are designed to prevent any melting of the fuel elements. Flooding of a reactor with seawater furnishes additional cooling for the fuel elements and so provides added protection against the release of radioactive fission products.

Radiation measurements, water samples, bottom sediment samples, and debris collected from the area where THRESHER sank were analyzed for radioactivity shortly after the sinking and again in 1965 by various laboratories. Similarly, seawater and bottom sediment samples taken near SCORPION's hull were analyzed for radioactivity. In 1977, 1983, 1986, and 1998, follow-up samples of water, sediment, and marine life were collected from near the THRESHER debris. In 1979, 1986, and 1998, follow-up samples of water, sediment, and marine life were collected from near the SCORPION debris. None of these samples showed any evidence of release of radioactivity from the reactor fuel elements in either THRESHER or SCORPION.

Cobalt 60 released from both THRESHER and SCORPION coolant systems was detectable at low levels in the sediment samples in the debris areas. Cobalt 60 was not detectable in samples of water or marine life. The maximum cobalt 60 concentration measured in the sediment at either site during the 1998 survey was 2.02 picocuries per gram; most samples were much less than this concentration. This is less than one-tenth of the concentration of naturally occurring radioactivity in the sediment. For perspective, if a person's diet contained cobalt 60 at the maximum concentration detected in the sediment, that person would receive less than 10 percent of the radiation exposure received from natural background radioactivity.

SCORPION carried two torpedoes with nuclear weapons containing plutonium. While the monitoring campaign was for the express purpose of assessing the impacts from the nuclear reactor, sediment, water, and marine life samples collected at the SCORPION site in 1986 and 1998 were also analyzed for plutonium. Total plutonium radioactivity concentrations and the relative concentrations of plutonium isotopes were typical of background concentrations due to fallout from nuclear weapons testing. Thus, there is no evidence of leakage of plutonium from nuclear weapons that were on the submarine when it sank.

Summary information on the radiological surveys of the THRESHER and SCORPION sites was published in reference 23. In 1993, the Navy issued detailed unclassified reports of the radiological environmental monitoring of the THRESHER and SCORPION sites, references 24 and 25. The Navy also released a report in 2000 of the environmental monitoring conducted in 1998, reference 26. The conclusions of this report

confirm the results of previous environmental monitoring expeditions and demonstrate that the THRESHER and SCORPION have had no discernible effect on the radioactivity in the environment.

SOLID RADIOACTIVE WASTE DISPOSAL

During maintenance and overhaul operations, solid low-level radioactive wastes (consisting of contaminated rags, plastic bags, paper, filters, ion exchange resin and scrap materials) are collected from nuclear-powered ships and their support facilities. These low-level radioactive materials are required to be strictly controlled to prevent loss. These controls include naval accountability procedures, which require serialized tagging and marking and signatures by radiologically trained personnel.

Table 1 summarizes the total radioactivity and volumes of radioactive solid waste disposed of during the last 5 years. Table 1 includes all waste generated by U.S. naval nuclear-powered ships and the listed support facilities because all radioactive solid waste generated by U.S. nuclear-powered ships is transferred to the listed facilities. The quantity of solid radioactive waste in any one year from a particular facility depends on the amount and type of support work performed that year. Table 1 does not include spent fuel or other classified radioactive components shipped to Department of Energy facilities.

Figure 2 shows that the total annual volume of solid low-level radioactive waste was substantially reduced in the 1970's, despite increasing numbers of nuclear-powered ships. This reduction was accomplished simultaneously with reduction in personnel radiation exposure, as described in reference 27. This reduction was accomplished by several techniques, including a total containment concept for radiological work, which minimizes the spread of radioactivity to non-radioactive materials; use of preplanning and mockups to minimize rework; reusing rather than disposing of tools and equipment; use of radioactive liquid processing procedures that minimize depletion of processing media; use of compaction equipment and efficient packaging to fully use space in disposal containers; use of licensed commercial radioactive waste incineration, compaction, and radioactive metal recycling services; and separating solid waste that requires special disposal owing to its radioactive content from that which does not. The latter is achieved by work site controls and by use of sensitive equipment to detect radioactivity only slightly greater in concentration than that found in natural materials such as soil, rocks, water, and biological matter (see reference 18), thus requiring the material to be handled as radioactive for waste disposal purposes. Material that passes the screening provided by this sensitive detection equipment can be disposed of as ordinary waste. Challenging goals are set by each shipyard to ensure continuing management attention to minimizing the generation of waste in radiological work.

The annual volume of solid low-level radioactive waste disposed of in 2000 by the entire Naval Nuclear Propulsion Program, as shown in Table 1, could be contained in a

cube measuring about 10 yards on a side. The total annual volume is approximately 2 percent of the total volume of solid low-level radioactive waste buried in commercial disposal sites in the States of Washington, South Carolina, and Utah each year (reference 28).

Solid radioactive waste materials are packaged in strong, tight containers, shielded as necessary, and shipped to burial sites licensed by the U.S. Nuclear Regulatory Commission or a State under agreement with the Nuclear Regulatory Commission. Solid radioactive materials from naval nuclear-powered ships have not been dumped at sea since 1970, when the Navy issued procedures prohibiting sea disposal of solid radioactive materials. Shipyards and other shore facilities have never been permitted to dispose of radioactive solid wastes by burial on their own sites.

The Low-Level Radioactive Waste Policy Amendments Act of 1985 establishes that the States are responsible, either individually or in multi-State compacts, for providing for the disposal of low- level radioactive waste from private and non-Department of Energy Federal Government generators. Under this law, a waste compact may prohibit disposal of waste from outside the compact. The Northwest Compact site in Richland, Washington, accepts waste only from the Northwest and Rocky Mountain Compacts, which include Navy facilities in Washington and Hawaii.

The Atlantic Compact site in Barnwell, South Carolina, currently accepts waste from every State. Over the next eight years, however, the Barnwell site will limit waste acceptance from out-of-compact generators.

One other disposal site accepts low-level radioactive waste. A disposal site in Clive, Utah, is licensed by the State of Utah and is accessible to generators around the country, but is only licensed to accept waste with low concentrations of radioactivity.

In view of the increased disposal fees and the uncertain future of low-level radioactive waste disposal sites, a concerted effort was made in the early 1990's to reevaluate radioactive equipment in storage for potential future use and to dispose of that equipment for which no specific future need was identified. For example, some of this equipment was no longer needed due to the declining Fleet size. In addition, the closure of Mare Island and Charleston Naval Shipyards resulted in the disposal of much of the equipment from these facilities. The volume of low-level radioactive waste shipped from these two shipyards accounted for 66 percent of the total volume shipped during 1995. As a result of all of these factors, the amount of solid low-level radioactive waste shipped for disposal increased from 1990 through 1995, but has declined in recent years.

Table 1: Disposed Radioactive Solid Waste from U.S. Naval Nuclear-Powered Ships and Their Support Facilities for 1996 through 2000

FACILITY	1996		1997		1998		1999		2000	
	THOUSAND CUBIC FEET	CURIES	THOUSAND CUBIC FEET	CURIES	THOUSAND CUBIC FEET	CURIES	THOUSAND CUBIC FEET	CURIES	THOUSAND CUBIC FEET	CURIES
Kittery, Maine Portsmouth Naval Shipyard	1	58	1	12	1	18	2.0	17	1.2	1
Groton, New London, Connecticut Electric Boat Division, Naval Submarine Base	1	2	1	<1	1	1	0.6	<1	1.5	<1
Newport News, Virginia Newport News Shipbuilding	2	1	1	4	1	2	2.3	18	1.7	1
Norfolk, Virginia Naval Shipyard and Tenders	7	114	4	47	3	56	5.1	46	1.9	69
Charleston, South Carolina Naval Shipyard and Tenders	1	<1	—	—	—	—	—	—	—	—
Vallejo, California Mare Island Naval Shipyard	4	<1	—	—	—	—	—	—	—	—
San Diego, California Navy Bases	—	—	—	—	—	—	1.0	12	0.1	<1
Bremerton, Washington Puget Sound Naval Shipyard	18	47	13	16	14	49	15.7	45	20.1	42
Pearl Harbor, Hawaii Naval Shipyard and Intermediate Maintenance Facility	1	1	1	26	2	48	2.1	88	1.8	101
TOTAL	35	225	21	106	22	174	28.8	227	28.3	216

NOTES:

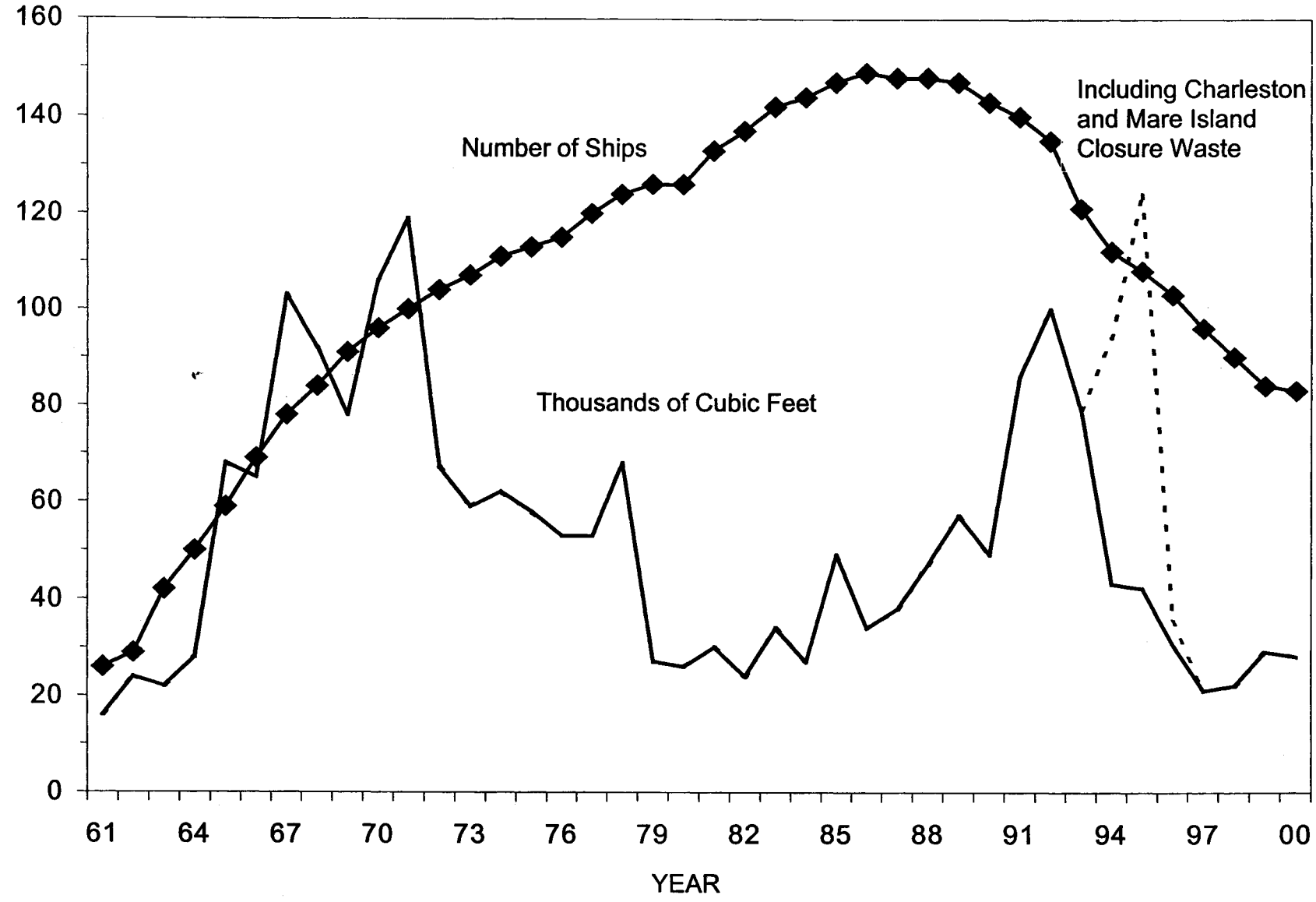
(1) This table includes all radioactive waste from tenders and nuclear-powered ships. This radioactivity is primarily cobalt 60. This radioactive waste is shipped to burial facilities licensed by the U.S. Nuclear Regulatory Commission or a State.

(2) Prior to 1999, volumes less than 500 cubic feet are reported as 1 thousand cubic feet. In 1999, volumes less than 100 cubic feet are reported as 0.1 thousand cubic feet. Activities less than 0.5 curie are reported as <1 curie.

(3) San Diego waste was included with Mare Island Naval Shipyard in 1996 and with Puget Sound Naval Shipyard in 1997 and 1998.

Figure 2:

Radioactive Solid Waste Disposal in the Naval Nuclear Propulsion Program 1961 - 2000



Deactivation of Ingalls Shipbuilding Radiological Facilities

From 1958 to 1980, Ingalls Shipbuilding was engaged in the construction and overhaul of naval nuclear-powered ships in Pascagoula, Mississippi. The shipyard radiological facilities that supported this work were deactivated between 1980 and 1982 by removing and disposing all radioactive material associated with naval nuclear propulsion plants. Useful items, such as tools and equipment that were radioactively contaminated, were transferred to other organizations in the Naval Nuclear Propulsion Program. The remaining radioactive material was disposed of as solid waste.

Extensive radiological decommissioning surveys were performed to verify the removal of this radioactive material. Direct radiological surveys were performed on over 274,000 square feet of building and facility surfaces. Over 11,000 samples of these surfaces (as well as soil, ground cover, and concrete) were taken from all areas where radioactive work was previously performed. These samples were analyzed using sensitive laboratory equipment. In addition, both the State of Mississippi and the U.S. Environmental Protection Agency (reference 29) performed overcheck surveys of the deactivated facilities. After these surveys were completed, the Ingalls facilities were released for unrestricted use. Personnel who subsequently occupy these facilities will not receive measurable radiation exposure above natural background levels that exist in areas not affected by naval nuclear propulsion plant work. Reference 29 is the report of the survey of the Ingalls facilities by the Environmental Protection Agency (EPA).

Closure of Charleston and Mare Island Naval Shipyards

Mare Island Naval Shipyard was engaged in the construction, overhaul, and refueling of naval nuclear-powered ships from 1956 to 1995. Charleston Naval Shipyard was engaged in overhaul and refueling of naval nuclear-powered ships from 1962 to 1994. The 1993 round of the Base Closure and Realignment Act process directed closure of these shipyards. The radiological facilities at both Charleston and Mare Island have been deactivated in a manner similar to the process followed for deactivation of radiological facilities at Ingalls Shipbuilding. The shipyards were closed in April 1996.

As at Ingalls, extensive radiological decommissioning surveys were performed to verify the removal of radioactive material. At each shipyard, direct radiological surveys were performed on over 5 million square feet of building and facility surfaces, and over 40,000 samples of soil, ground cover, and concrete were analyzed using sensitive laboratory equipment. No cobalt 60 was detected, other than trace concentrations in a few localized areas. Simple, proven cleanup methods were used to remediate these areas. Both the radiological deactivation work and the survey work were performed by shipyard workers. The total amount of Program radioactivity remediated at each shipyard was about the same as that in a typical household smoke detector (2 to 3 microcuries).

The Navy's radiological verification surveys were completed in March 1996. Both the EPA and the States reviewed the Navy's survey data, conducted overcheck surveys, and agree with the Navy's results. Personnel who occupy these facilities will not receive measurable radiation exposure above natural background levels.

The successful radiological deactivation and closures of Ingalls radiological facilities in 1982 and of Charleston and Mare Island in 1996 demonstrate that the stringent control over radioactivity exercised by the Naval Nuclear Propulsion Program from its inception has been successful in preventing radiological contamination of the environment and in avoiding expensive radiological liabilities at shipyards.

Mixed Radioactive and Hazardous Waste

Waste that is both radioactive and chemically hazardous is regulated under both the Atomic Energy Act and the Resource Conservation and Recovery Act (RCRA) as "mixed waste." Within the Naval Nuclear Propulsion Program, concerted efforts are taken to avoid commingling radioactive and chemically hazardous substances so as to minimize the potential for generation of mixed waste. For example, these efforts include avoiding the use of acetone solvents, lead-based paints, lead shielding in disposal containers, and chemical paint removers. As a result of Program efforts to avoid the use of chemically hazardous substances in radiological work, Program activities typically generate each year less than 35 cubic meters of mixed waste that requires off-site treatment following completion of on-site processing. As of the end of 2000, about 60 cubic meters of Program mixed waste is stored pending the availability of Department of Energy (DOE) and commercial mixed waste treatment capacity required to deal with over 600,000 cubic meters of non-Program DOE mixed waste. Mixed Waste Site Treatment Plans, approved by applicable Federal and State regulators pursuant to the requirements of the 1992 Federal Facility Compliance Act, identify specific treatment plans for each type of Program mixed waste.

Disposal of Decommissioned, Defueled Naval Reactor Plants

During the 1980's, the nuclear-powered submarines constructed in the 1950's and 1960's began to reach the end of their service life. In 1982, the Navy, with the DOE as a cooperating agency, published a Draft Environmental Impact Statement (EIS) on the disposal of decommissioned, defueled naval submarine reactor plants. The Draft EIS was widely distributed to individuals, environmental organizations, State and local officials, and other Federal agencies. All substantive comments were analyzed and addressed in the Final EIS, which was issued in 1984 (reference 23). Although the Navy had evaluated the option of disposing of the defueled ships by sinking at sea, the preferred option identified in the Final EIS was to dispose of the defueled reactor plants at a Federal disposal facility already used for low-level radioactive waste disposal. In December 1984, the Secretary of the Navy issued a Record of Decision to proceed with land disposal. In 1996, the Navy

issued a Final EIS (reference 30) which evaluated the disposal of defueled reactor plants from cruisers and newer submarine classes. The Navy and the DOE issued a Record of Decision to dispose of these defueled reactor plants by land disposal in the same manner.

A nuclear-powered ship is constructed with the nuclear power plant inside a single section of the ship, called the reactor compartment. Before the reactor compartment is disposed of, the nuclear fuel is removed and handled in the same manner as nuclear fuel removed during refueling of nuclear-powered ships. The defueled reactor compartments are removed from decommissioned nuclear-powered ships in drydocks at the Puget Sound Naval Shipyard in Bremerton, Washington. After removal from a ship, the reactor compartment is sealed and loaded onto a barge for transport to the Port of Benton on the Columbia River near the Department of Energy Hanford Site. At the Port of Benton, the reactor compartment is transferred to a land transporter, which carries the reactor compartment to the disposal trench on the Hanford Site. Further information on this process is contained in the Final EIS (reference 30). The first defueled reactor compartment was shipped to Hanford in 1986. In 2000, 8 defueled reactor compartments were shipped, bringing the total number shipped to 94.

TRANSPORTATION OF RADIOACTIVE MATERIAL

Shipments of radioactive materials in the Naval Nuclear Propulsion Program must be made in accordance with applicable regulations of the U.S. Department of Transportation, the Department of Energy, and the Nuclear Regulatory Commission (NRC). The purpose of these regulations is to ensure that shipments of radioactive material are adequately controlled to protect the environment and the health and safety of the general public. These regulations apply to all radioactive material shipments and provide requirements for container design, certification, and identification pertaining to the specific quantity, type, and form of radioactivity being shipped.

In addition to the above, requirements for naval shipping container designs incorporate shielding and integrity specifications. These requirements provide for container design analysis, training and qualification of workers who construct containers, and quality control inspections during fabrication to ensure the containers will meet design requirements.

In addition to imposing requirements of Federal transportation regulations, the Navy has issued standard instructions to further control shipments of radioactivity associated with U.S. naval nuclear propulsion plants. These standard instructions result in a quality assurance program that includes inspections and assessments by independent organizations and senior management. Organizations making shipments are required to prepare local procedures, which direct the use of compliance checklists and management review to ensure compliance with applicable Department of Transportation, Navy, and

disposal site requirements. Only specially trained, designated people, knowledgeable in shipping regulations, are permitted to authorize shipments of radioactive material.

Protective transportation services, such as signature security service or sealed shipping vehicles, are required for these shipments to ensure point-to-point control and traceability of each shipment from shipper to receiver. A readily accessible log of all shipments in transit is maintained to enable prompt identification and provide the basis for advice on the nature of the shipment. Receivers must make return receipts in writing to ensure that radioactive material has not been lost in shipment. Inspection of containers of radioactive material and accompanying documents is required promptly after receipt to monitor compliance. Receivers must report even minor discrepancies from detailed shipping regulations to the shipper, so that correction can be made in future shipments. This is done to ensure compliance with shipping regulations.

Radioactive materials shipped in the Naval Nuclear Propulsion Program include anticontamination clothing for laundry, small sealed sources used for calibrating radiation monitoring instruments, tools and equipment used for radioactive work, low-level radioactive waste, radioactive components, and new and spent naval fuel. A total of approximately 1,000 shipments are made annually by naval nuclear-powered ships and their support facilities, which is a small part of the more than 2 million shipments of radioactive materials made annually in the United States (reference 31).

In the Naval Nuclear Propulsion Program, nearly all radioactive shipments contain only low-level radioactivity and are classified under Department of Transportation regulations as low specific activity, surface contaminated object, or limited quantity shipments. The predominant radionuclide associated with these shipments is cobalt 60 in the form of insoluble metallic oxide corrosion products attached to surfaces of materials inside shipping containers. Most low-level shipments are made by truck. Air shipments, used occasionally, involve only very low-level radioactivity and are not shipped on passenger planes.

Approximately one-fourth of the low-level radioactivity shipments are minute quantities in sealed instrument calibration check sources. These sources contain insignificant quantities of radioactivity, comparable to the radioactivity in typical ionization-type smoke detectors. More than half the low-level shipments are anticontamination clothing, equipment, tools, and routine waste. The anticontamination laundry involves shipments of special outer clothing potentially contaminated with low levels of radioactivity while worn in controlled work areas. This laundry is shipped to NRC or agreement State-licensed contractors for cleaning. On average, one shipment of low-level radioactive waste is made every two months from each facility listed in Table 1. About one-fourth of the low-level shipments are environmental and chemistry samples enroute to analytical laboratories.

The remaining few shipments are new and spent naval fuel and radioactive components associated with reactors, and these are shipped by the Department of Energy. Such shipments are made infrequently because naval nuclear-powered ships currently require at most one refueling during their service life. Measures are carried out to help safeguard these shipments and ensure they reach their destination. Each spent naval fuel shipment is escorted by U.S. Government representatives, and each shipping container is specifically designed to withstand extreme accident impacts, to withstand fire and water immersion, and to prevent release of the material to the environment in the event of an accident. The cargo in the nuclear fuel and radioactive component shipments is non-explosive and non-flammable; in addition, the radioactive material in these components is insoluble and therefore should not be dispersed even if there were an accident.

Since 1957, all spent fuel removed from naval reactors has been shipped to the DOE's Idaho National Engineering and Environmental Laboratory (INEEL) for examination. Until 1992, naval spent fuel was reprocessed by the DOE after examination. In 1992, the DOE ceased reprocessing operations. Since then, post-examination naval spent fuel has been temporarily stored at INEEL pending the availability of a permanent repository or centralized interim storage site. Continued shipment of naval spent fuel to INEEL for examination and temporary storage was fully evaluated in a comprehensive DOE spent fuel management EIS, published in April 1995 (reference 32). (The Navy participated as a cooperating agency). Under the Record of Decision for this EIS and a court-ordered agreement among the Navy, the DOE, and the State of Idaho, naval spent fuel will continue to be shipped to INEEL through 2035 for examination, and it will be temporarily stored there until it can be shipped to a permanent geologic repository for burial or a centralized interim storage site outside Idaho for storage as soon as either facility is available.

Estimates of annual radiation exposure to transportation crews and the general public from shipments of radioactive materials in the Naval Nuclear Propulsion Program have been made in a manner consistent with that employed by the NRC in reference 31. Based on comparisons of the types and numbers of radioactive shipments made, the total annual radiation exposure to all transportation crews for all shipments is estimated to be less than 3 person-rem. If one person were to receive all this exposure, that person would not exceed the annual radiation exposure permitted for an individual worker by NRC. The total estimated radiation exposure accumulated by the public along transportation routes is 10 person-rem. The maximum exposure to any individual member of the public would be far less than that received from natural radiation.

For naval spent fuel shipments, more detailed exposure estimates are described in the DOE spent fuel management EIS cited above (reference 32) and in the Department of the Navy spent fuel container system Environmental Impact Statement published in November 1996 (reference 33). The analyses described in these EIS's demonstrate that

for the 735 container shipments of spent fuel made through the end of 2000, the total population dose is about 3 person-rem.

Shipments of radioactive materials associated with naval nuclear propulsion plants have not resulted in any measurable release of radioactivity to the environment. There have never been any significant accidents involving release of radioactive material during shipment since the Naval Nuclear Propulsion Program began. In general, the few accidents that have occurred involved incidents such as broken truck axles or slight external damage to a shipping container with no release of radioactivity. In one incident a train collision resulted in minor denting of a new fuel shipping container; despite this damage, there was no loss of integrity of the container, no damage to the fuel, and no release of radioactivity. In the only two instances that involved loss of contents, one-quart containers holding samples with small amounts of radioactivity were broken in shipment. In one case this occurred when a cargo aircraft crashed. The other container was lost from a commercial ship. Both containers were recovered, and there was no measurable radioactivity released since the original contents were less than a microcurie.

The requirements of the Naval Nuclear Propulsion Program specify that the carriers for all radioactive material shipments shall have accident plans that identify the actions to be taken in case the transportation vehicle is involved in an accident. These plans provide for notification of civil authorities and the originating facility. Also provided is a 24-hour telephone number at the originating facility for emergency guidance and assistance. The U.S. Navy would communicate with and cooperate fully with State radiological officials in the event of occurrences involving shipments of radioactive materials.

ENVIRONMENTAL MONITORING

To provide additional assurance that procedures used by the U.S. Navy to control radioactivity are adequate to protect the environment, the Navy conducts environmental monitoring in harbors frequented by its nuclear-powered ships. Environmental monitoring surveys for radioactivity are periodically performed in harbors where U.S. naval nuclear-powered ships are built or overhauled and where these ships have home ports or operating bases. Samples from each harbor monitored are also checked at least annually by a DOE laboratory to ensure analytical procedures are correct and standardized. The DOE laboratory findings have been consistent with those of the shipyards.

Navy Environmental Monitoring Program

The Navy environmental monitoring program consists of analyzing samples of harbor sediment, water, and marine life, supplemented by shoreline surveys, dosimeters, and effluent monitoring. Sampling harbor sediment and water each quarter is emphasized because these materials would be the most likely affected by releases of radioactivity.

As discussed earlier, cobalt 60 is the predominant radionuclide of environmental interest resulting from naval nuclear reactor operations. Therefore, Navy monitoring procedures require collecting in each harbor approximately 10 to 100 sediment samples once each quarter for analysis to detect cobalt 60 and other gamma-emitting radionuclides. Locations and numbers of sediment samples for a particular harbor depend on the size of the harbor and the number and separation of locations where nuclear-powered ships berth. Sampling points are selected to form a pattern around ship berthing locations and to provide points in areas away from these berthing locations. The sampling locations selected are based on the individual characteristics of each harbor.

Sediment samples are collected using a dredge that samples a surface area of 36 square inches and has been modified to collect only the top layer of sediment (about an inch). The top layer was selected because it should be more mobile and more accessible to marine life than deeper layers. The samples are drained of excess water and put directly into a Marinelli container for analysis. Each sediment sample is analyzed for gamma radioactivity in the container in which it is collected, using a solid-state germanium detector with a multichannel analyzer. The gamma data are analyzed specifically for the presence of cobalt 60. Results of the sediment samples from harbors monitored by the Navy in the U.S. and its possessions are summarized in Table 2.

Table 2 shows that most harbors do not have detectable levels of cobalt 60. As reported in the past, low levels of cobalt 60, less than 3 picocurie per gram, are detected around a few operating base and shipyard piers where nuclear-powered ship maintenance and overhauls were conducted in the early 1960's. These low levels are well below the naturally occurring radioactivity levels in the harbors. The radioactivity detected is from operations in the early 1960's. As discussed previously, from 1971 to 2000 the total long-lived gamma radioactivity released each year within 12 miles from shore from all U.S. naval nuclear-powered ships and their support facilities has been less than 0.002 curie. This low release amount is too small to be detectable in the harbors. A measure of the significance of these low levels is that if all of a person's food (reference 34) were to contain 3 picocurie of cobalt 60 per gram, that person would receive less than 10 percent of the dose from natural background radiation (see reference 18). Cobalt 60 is not detectable in general harbor bottom areas away from these piers.

Low levels of cesium 137 were detected in some sediment samples. The cesium 137 detected is not related to naval nuclear reactor operations, because the high integrity naval fuel retains fission products. The cesium 137 concentrations measured in the sediment are due to worldwide dispersion from weapons testing.

For comparison, references 35 and 36 contain evaluations by laboratories of the Georgia Department of Natural Resources and the Environmental Protection Agency of the effects on the environment from the accumulation of radionuclides near points of discharge from several nuclear facilities. The referenced reports conclude that radioactivity levels

much greater than those shown in Table 2 for Naval Nuclear Propulsion Program facilities have caused no significant radiation exposure to the general public.

The maximum total radioactivity observed in a U.S. harbor is less than 0.01 curie of cobalt 60. This radioactivity is small compared to background. Based on the typical concentrations of naturally occurring radioactivity such as potassium 40, radium, uranium, and thorium (which are described in reference 16 for marine sediment), the natural radioactivity in the sediment of a typical harbor amounts to hundreds of curies.

In addition to Navy analysis of environmental samples, at least nine sediment samples from each harbor monitored have been sent each year to a Department of Energy laboratory, as a check of Navy results. This Department of Energy laboratory provides a further check on the quality of environmental sample analyses by participating in the quality control programs sponsored by the Department of Energy Environmental Measurements Laboratory.

The check samples were analyzed for gamma radionuclides in a manner similar to Navy procedures but with greater sensitivity. Figure 3 depicts the gamma spectra for two such samples. Both spectra show the presence of abundant, naturally occurring radionuclides which contribute to measured radioactivity even if cobalt 60 were not present. The upper spectrum is for a sample to which cobalt 60 has been added to achieve a concentration of approximately 3 picocurie per gram and shows easily recognizable energy peaks due to the presence of this small concentration of cobalt 60. The lower spectrum is typical of most of the sediment samples with no detectable cobalt 60.

At least five water samples are taken in each harbor once each quarter in areas where nuclear-powered ships berth, as well as from upstream and downstream locations. These samples are analyzed for presence of gamma-emitting radionuclides, including cobalt 60. A solid-state germanium detector with a multichannel analyzer is used to measure gamma radioactivity and detect the presence of cobalt 60. Procedures for analysis will detect cobalt 60 if its concentration exceeds the Environmental Protection Agency drinking water limits of reference 14. No cobalt 60 has been detected in any of the water samples taken from any of the harbors monitored.

An Environmental Protection Agency evaluation in reference 37 shows that the cobalt 60 from naval nuclear propulsion plants is in the form of metallic corrosion product particles which do not appear to be concentrated in the food chain. However, samples of marine life such as mollusks, crustaceans, and marine plants have been collected from all harbors monitored. Marine life samples are also analyzed using a germanium detector with a multichannel analyzer. The results of the marine life samples from harbors

Table 2: Summary of 2000 Surveys for Cobalt 60 in Bottom Sediment of U.S. Harbors Where U.S. Naval Nuclear-Powered Ships Have Been Regularly Based, Overhauled, or Built

Facility	Range of Cobalt 60 Analytical Results (pCi/gm)	Number of Samples with Cobalt 60		Total Bottom Area with Cobalt 60 greater than 3 pCi/gm (square kilometers)
		less than 3 pCi/gm	greater than 3 pCi/gm	
Kittery, Maine Portsmouth Naval Shipyard	<0.01 – <0.13	120	0	0
Groton, New London, Connecticut Electric Boat Division, Naval Submarine Base	<0.01 – 0.08	384	0	0
Newport News, Virginia Newport News Shipbuilding	<0.02 – <0.13	188	0	0
Norfolk, Virginia Naval Shipyard and Station	<0.02 – <0.05	280	0	0
Charleston, South Carolina Naval Nuclear Power Training Unit	<0.01 - <0.02	36	0	0
Kings Bay, Georgia	<0.01 – <0.02	100	0	0
San Diego, California Navy Bases	<0.01 - <0.04	252	0	0
Puget Sound, Washington Naval Shipyard and Bases	<0.01 – <0.06	392	0	0
Pearl Harbor, Hawaii Naval Shipyard and Intermediate Maintenance Facility	<0.01 – 0.08	208	0	0
Apra Harbor, Guam	<0.01 – <0.02	108	0	0
Port Canaveral, Florida	<0.01 – <0.02	80	0	0

NOTES:

(1) The less-than symbol [<] indicates that no cobalt 60 was detected in the sample. The number given is the minimum detectable concentration (MDC); i.e., the concentration at which cobalt 60 could be detected if it were present. The MDC varies from sample to sample and location to location due to differences in the amount of naturally occurring radioactivity in each sample, differences in the weight of the sample, detection equipment differences, and statistical fluctuations.

(2) pCi/gm = picocurie per gram. 1 pCi = $1x10^{-12}$ curie (Ci).

(3) One square kilometer is approximately 0.4 square mile. Estimated total cobalt 60 in the top layer of sediment is 0.01 Ci. Samples from more than one foot deep from several harbors show that cobalt 60 present may be two to five times that measured in the surface layer.

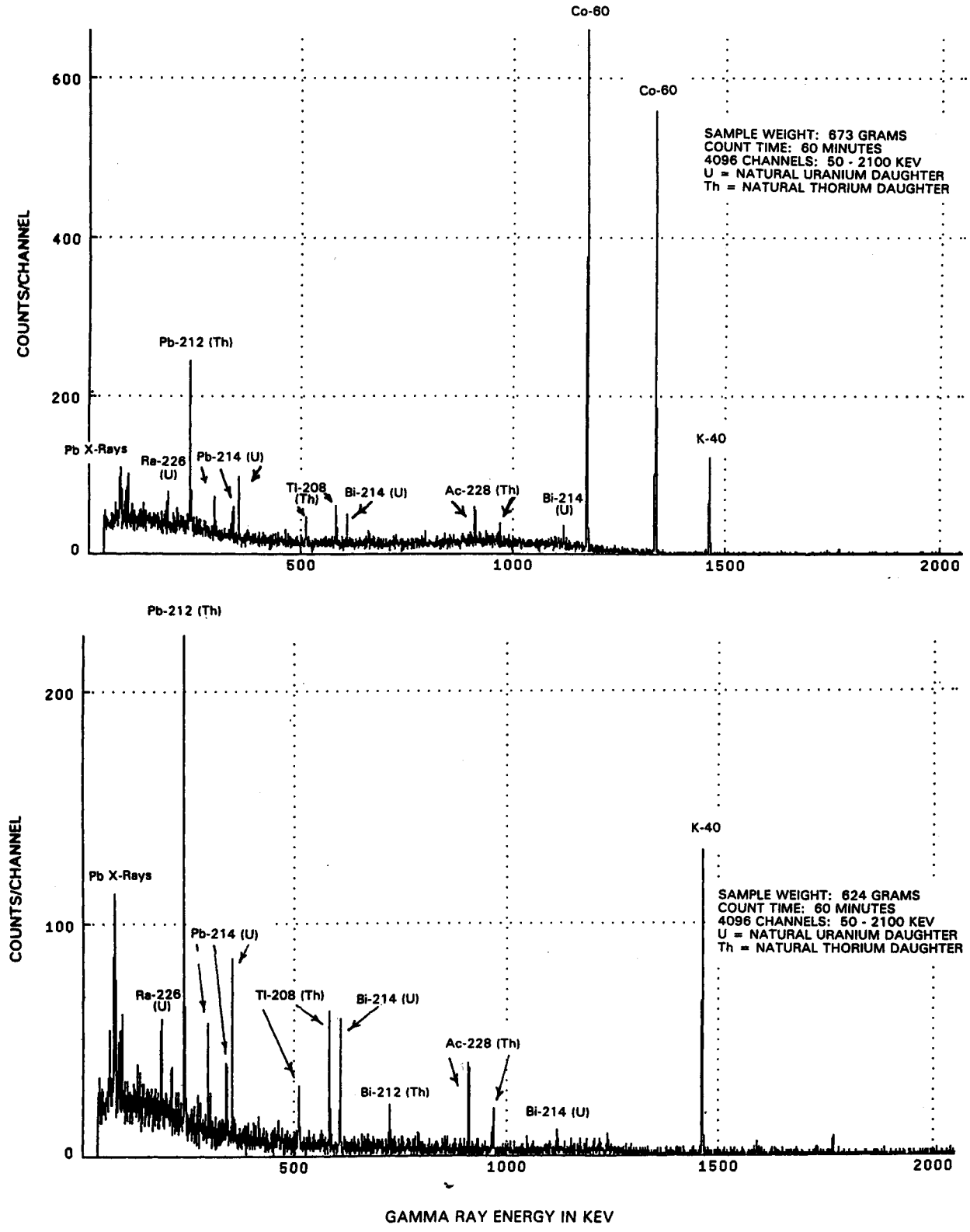


Figure 3:
Gamma Spectra of Harbor Bottom Sediment Samples
with a Germanium Detector

monitored by the Navy in the U.S. and possessions are summarized in Table 3. Table 3 demonstrates that no buildup of cobalt 60 associated with U.S. naval nuclear-powered ships has been detected in these samples of marine life.

In all monitored harbors, shoreline areas uncovered at low tide are surveyed twice per year for radiation levels, using sensitive scintillation detectors to determine if any radioactivity from bottom sediment washed ashore. All results were the same as background radiation levels in these regions, approximately 0.01 millirem per hour. Thus, there is no evidence in these ports that these areas are being affected by the operation of nuclear-powered ships.

Ambient radiation levels are continuously measured using sensitive thermoluminescent dosimeters posted at locations outside the boundaries of areas where radiological work is performed. These dosimeters are also posted at locations remote from support facilities to measure background radiation levels from natural radioactivity. The results of dosimeters posted at support facilities between radiologically controlled areas and the general public and dosimeters posted at remote background locations up to several miles away are compared in Table 4. The range of dosimeter readings is also given: natural background radiation levels vary from location to location primarily due to the concentration of radionuclides in the soil (reference 18). Table 4 shows that Naval Nuclear Propulsion Program activities had no distinguishable effect on normal background radiation levels at the site perimeter.

Naval nuclear reactors and their support facilities are designed to ensure that there are no significant discharges of radioactivity in airborne exhausts. Radiological controls are exercised in support facilities to preclude exposure of working personnel to airborne radioactivity exceeding one-tenth of the limits specified in reference 6. These controls, discussed in reference 28, include containment for radioactive materials and provide a barrier to prevent significant radioactivity from becoming airborne. Further, all air exhausted from these facilities is passed through high efficiency particulate air (HEPA) filters and monitored during discharge. Comparison of sensitive airborne radioactivity measurements in shipyards demonstrates that air exhausted from facilities actually contained a smaller amount of particulate radioactivity than it did when it was drawn from the environment.

Table 3: Summary of 2000 Surveys for Cobalt 60 in Marine Life of U.S. Harbors Where U.S. Naval Nuclear-Powered Ships Have Been Regularly Based, Overhauled, or Built

Facility	Mollusks	Crustaceans	Marine Plants
	Cobalt 60 Analytical Results (pCi/gm)	Cobalt 60 Analytical Results (pCi/gm)	Cobalt 60 Analytical Results (pCi/gm)
Kittery, Maine Portsmouth Naval Shipyard	<0.03	<0.03	<0.03
Groton, New London, Connecticut Electric Boat Division, Naval Submarine Base	<0.07	<0.07	<0.08
Newport News, Virginia Newport News Shipbuilding	<0.05	<0.09	<0.08
Norfolk, Virginia Naval Shipyard and Station	<0.03	<0.04	<0.06
Charleston, South Carolina Naval Nuclear Power Training Unit	<0.01	<0.01	N/A
Kings Bay, Georgia	<0.01	<0.01	<0.01
San Diego, California Navy Bases	<0.01	<0.01	<0.04
Puget Sound, Washington Naval Shipyard and Bases	<0.05	<0.04	<0.05
Pearl Harbor, Hawaii Naval Shipyard and Intermediate Maintenance Facility	No Sample Available	<0.06	<0.05
Apra Harbor, Guam	<0.01	<0.01	<0.01
Port Canaveral, Florida	<0.01	<0.01	No Sample Available

NOTES:

(1) The less-than symbol [<] indicates that no cobalt 60 was detected in the sample. The number given is the minimum detectable concentration (MDC); i.e., the concentration at which cobalt 60 could be detected if it were present. The MDC varies from sample to sample and location to location due to differences in the amount of naturally occurring radioactivity in each sample, differences in the weight of the sample, detection equipment differences, and statistical fluctuations.

(2) pCi/gm = picocurie per gram. 1 pCi = $1x10^{-12}$ curie (Ci)

Table 4: Summary of 2000 Off-Site and Perimeter Radiation Monitoring of U.S. Harbors Where U.S. Naval Nuclear-Powered Ships Have Been Regularly Based, Overhauled or Built

FACILITY	Average Off-site Dosimeter (mrem/qtr)	Range of Off-site Dosimeter (mrem/qtr)	Average Perimeter Dosimeter (mrem/qtr)	Range of Perimeter Dosimeter (mrem/qtr)
Kittery, Maine Portsmouth Naval Shipyard	19	16 – 23	19	15 – 27
Groton, New London, Connecticut Electric Boat Division, Naval Submarine Base	29	21 – 37	26	14 – 39
Newport News, Virginia Newport News Shipbuilding	16	10 – 29	14	10 – 20
Norfolk, Virginia Naval Shipyard and Station	26	19 – 32	18	12 – 29
Charleston, South Carolina Naval Nuclear Power Training Unit	18	9 – 27	17	11 – 21
Kings Bay, Georgia	20	14 – 28	21	15 – 27
San Diego, California Navy Bases	27	20 – 35	22	15 – 29
Puget Sound, Washington Naval Shipyard and Bases	16	13 – 18	16	13 – 19
Pearl Harbor, Hawaii Naval Shipyard and Intermediate Maintenance Facility	21	16 – 25	20	16 – 23
Apra Harbor, Guam	17	12 – 22	18	12 – 37
Port Canaveral, Florida	18	12 – 35	19	14 – 23

NOTES:

(1) mrem/qtr = millirem per quarter year. 1 mrem = $1x10^{-3}$ rem.

ENVIRONMENTAL PATHWAYS ANALYSIS

Results of monitoring of environmental samples described above show that environmental radioactivity levels have not changed appreciably; therefore, radiation exposure to the public from operations of nuclear-powered ships and their support facilities is too low to measure. Nevertheless, an analysis has been performed to provide a quantitative estimate of the radiation to which any member of the general public might be exposed as a result of radioactivity in liquid and airborne effluents.

For analysis of airborne effluents, the EPA COMPLY computer program is used, as required by EPA regulations in reference 38. Site-specific input parameters include radionuclide releases, distance to members of the public, wind speed and direction, and food production. The releases of airborne effluents used in the analysis are summarized in Table 5. Cobalt 60 values include actual measurements of cobalt 60 emissions from the exhaust of Navy facilities, in addition to estimates of other potential sources of cobalt 60. Estimated values for other airborne radionuclides are based upon detailed study of land-based naval nuclear propulsion prototype plants, nuclear-powered ships, and their support facilities.

Results of the airborne effluent analysis are summarized in Table 6. Table 6 compares the estimated maximum exposure to a member of the public from Program effluents with guidelines of the NRC in reference 13. These numerical guidelines on calculated radiation exposures implement the concept that radioactivity in effluents from light water nuclear electric power reactors should be limited to amounts and quantities as low as reasonably achievable. Although these guidelines are not applicable to nuclear-powered ships and their support facilities, they provide a context in which to judge the significance of radiation exposures from Program effluents. The estimated maximum radiation exposure to a member of the general public from releases of airborne radioactivity is also much less than the standard of 10 millirem per year established by the EPA in reference 38.

Table 5: Radionuclide Releases Used for Environmental Pathways Analysis

Radionuclide	Annual Airborne Release (Curies)
Cobalt 60*	<0.0004
Tritium*	<1.5
Carbon 14*	<20
Krypton 83m	0.011
Krypton 85m	0.027
Krypton 85	0.000023
Krypton 87	0.035
Krypton 88	0.055
Xenon 131m	0.0015
Xenon 133m	0.012
Xenon 133	0.30
Xenon 135	0.33
Argon 41	3.3
Iodine 131	0.0000050
Iodine 132	0.0000054
Iodine 133	0.000014
Iodine 135	0.0000097

* Site-specific values are used for these radionuclides. The tabulated values bound the site-specific values used in the analysis.

For liquid effluents, the results of the environmental monitoring samples demonstrate without the need for any detailed theoretical model calculations that there is no significant radiation exposure to members of the public. For example, the samples of marine life obtained from the immediate vicinity of shipyard piers and drydocks did not have any detectable cobalt 60, even with sensitive analysis. Even if cobalt 60 were assumed to be resent at concentrations just below the limits of detection shown in Table 5 and a person were to eat 40 pounds per year of mollusks and crustaceans caught directly from these areas, the person would receive much less than one millirem per year. Similarly, even though the Navy minimizes releases of radioactive liquids and there has never been any detectable cobalt 60 in harbor water, the water consumption pathway cannot result in any dose to the public since seawater is not used for drinking water consumption in the vicinity of these facilities. Thus, exposures to members of the public from the Naval Nuclear Propulsion Program liquid effluents are far less than the guidelines of the NRC, which are listed in Table 6.

Table 6: Estimated Maximum Radiation Exposure to an Individual for Assumed Liquid Releases from Airborne Radioactivity Releases from Shipyards Engaged in Naval Nuclear Propulsion Work

SOURCE	Maximum Exposure to an Individual	
	NRC Guideline (millirem/year)	Estimated Value (millirem/year)
From Radionuclides in Liquid Releases	3 whole body, or 10 any organ	< 1
From Gaseous Radionuclides in Airborne Releases	5 whole body, or 15 skin	< 1
From Other Radionuclides in Airborne Releases	15 any organ	< 1

SOURCE	Maximum Exposure to an Individual	
	EPA Regulation (millirem/year)	Estimated Value (millirem/year)
From Radioiodine in Airborne Releases	3	< 0.03
From Other Radionuclides in Airborne Releases	10	< 1

AUDITS AND REVIEWS

The requirements and procedures for control of radioactivity is an important part of the training programs for everyone involved with radioactivity in the Naval Nuclear Propulsion Program. Such training is part of the initial qualification of shipyard workers and of naval personnel assigned to ships and bases, and is required to be repeated regularly. Emphasis on this training is part of the concept that radiological control personnel alone cannot always cause radiological work to be well performed; production and operations personnel and all levels of management must be involved in the control of radioactivity.

Checks and balances of several kinds are also set up to help ensure control of radioactivity. Written procedures exist that require verbatim compliance. Radiological control personnel monitor various steps in radioactive waste processing. In each shipyard an independent organization, separate from the radiological control organization, audits all aspects of radioactive waste processing. Audits are performed by representatives from Naval Reactors Headquarters who are assigned full-time at each shipyard. Radiological control personnel from Headquarters also conduct periodic inspections of each shipyard. In addition, shipyards have made detailed assessments of the environmental effects of shipyard operations and have published reports on the results of these assessments. Similarly, there are multiple levels of audits and inspections for the other Navy shore facilities, tenders, and nuclear-powered ships, as well as for other radiologically controlled functions (such as transportation). Even the smallest audit findings are followed up to ensure proper recovery and permanent corrective actions are taken and to help minimize the potential for future deficiencies.

The policy of the Navy is to provide for close cooperation and effective communication with State radiological officials whenever there are occurrences that might cause concern because of radiological effects outside the ships or shore facilities. The Navy has reviewed radioactive waste disposal, radiological environmental monitoring, transportation, and other radiological matters with State radiological officials in the States where Navy nuclear-powered ships are based or overhauled. Although there were no occurrences in 2000 that resulted in radiological effects to the public outside these facilities, States were notified when inquiries showed public interest in the possibility that such events had occurred. The Navy has encouraged States to conduct independent radiological environmental monitoring in harbors where naval nuclear-powered ships are based or overhauled; the States' findings have been consistent with the Navy's.

An EPA laboratory has conducted detailed environmental surveys of selected U.S. harbors (references 29 and 39 - 47). This laboratory has performed these surveys in the harbors at Pascagoula, Mississippi; Charleston, South Carolina; Pearl Harbor, Hawaii; San Diego, Alameda, San Francisco, and Vallejo, California; New London and Groton, Connecticut; Newport News, Portsmouth, and Norfolk, Virginia; Kings Bay, Georgia; Kittery, Maine-Portsmouth, New Hampshire; and Bremerton and Bangor, Washington. EPA findings have been consistent with those of the Navy, and have concluded that operation of naval nuclear-powered ships has had no adverse impact on public safety or health.

CONCLUSIONS

1. The total long-lived gamma radioactivity in liquids released into all ports and harbors from the Naval Nuclear Propulsion Program was less than 0.002 curie in 2000. For perspective, 0.002 curie is less than the quantity of naturally occurring radioactivity in the volume of saline harbor water occupied by a single submarine.

2. No increase of radioactivity above normal background levels has been detected in harbor water during Navy and EPA monitoring of harbors where U.S. naval nuclear-powered ships are based, overhauled, or constructed.

3. Liquid releases from U.S. naval nuclear-powered ships and their support facilities have not caused a measurable increase in the general background radioactivity of the environment.

4. Low-level cobalt 60 radioactivity in harbor bottom sediment is detectable around a few operating base and shipyard piers from low-level liquid releases in the 1960's; however, these concentrations of cobalt 60 are less than the concentrations of naturally occurring radionuclides around these piers. Cobalt 60 is not detectable in general harbor bottom areas away from these piers. The maximum total radioactivity observed in a U.S. harbor, less than 0.01 curie of cobalt 60, is small compared to the naturally occurring radioactivity. Comparison to previous environmental data shows that these environmental cobalt 60 levels are decreasing.

5. Estimates of radiation exposures to members of the public from the Naval Nuclear Propulsion Program are far less than EPA environmental standards, NRC guidelines, or the exposure from natural background radioactivity.

6. Procedures used by the Navy to control releases of radioactivity from U.S. naval nuclear-powered ships and their support facilities have been effective in protecting the environment and the health and safety of the general public. Independent radiological environmental monitoring performed by the EPAand the States have confirmed the adequacy of these procedures. These procedures have ensured that no member of the general public has received measurable radiation exposure as a result of current operations of the Naval Nuclear Propulsion Program.

7. The successful radiological deactivation and closures of Ingalls Shipbuilding radiological facilities in 1982 and of Charleston and Mare Island Naval Shipyards in 1996 demonstrate that the stringent control over radioactivity exercised by the Naval Nuclear Propulsion Program from its inception has been successful in preventing radiological contamination of the environment and in avoiding expensive radiological liabilities at shipyards.

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APPENDIX

ENVIRONMENTAL MONITORING SURVEY CHARTS

Environmental monitoring survey charts for harbors monitored for radioactivity associated with U.S. naval nuclear-powered ships in the U.S. and possessions are listed below and included in this appendix. The sampling locations for harbor water and harbor sediment are shown. In addition, shoreline survey areas and the locations of posted dosimetry devices are shown on the figures.

Figure No.	Location
	California
1	U.S. Naval Air Station North Island, San Diego
2	U.S. Naval Submarine Base, San Diego
3	U.S. Naval Station, San Diego
	Connecticut
4	Electric Boat Corporation, Groton
5	U.S. Naval Submarine Support Facility, New London Harbor
	Florida
6	Port Canaveral
	Georgia
7	U.S. Naval Submarine Base, Kings Bay
	Guam
8	Apra Harbor
	Hawaii
9	Pearl Harbor Area
10	Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility - Shipyard Area, Pearl Harbor
11	Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility - Submarine Base Area, Pearl Harbor
	New Hampshire/Maine
12	Portsmouth Naval Shipyard

South Carolina

13 Naval Nuclear Power Training Unit, Charleston

Virginia

14 Newport News Shipbuilding, Newport News

15 Norfolk Naval Shipyard, Portsmouth

16 U.S. Naval Station, Norfolk

17 Norfolk-Portsmouth Virginia Area

Washington

18 Puget Sound Naval Shipyard

19 Bangor/Hood Canal

20 U.S. Naval Station, Everett

FIGURE 1
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL AIR STATION NORTH ISLAND, SAN DIEGO, CA

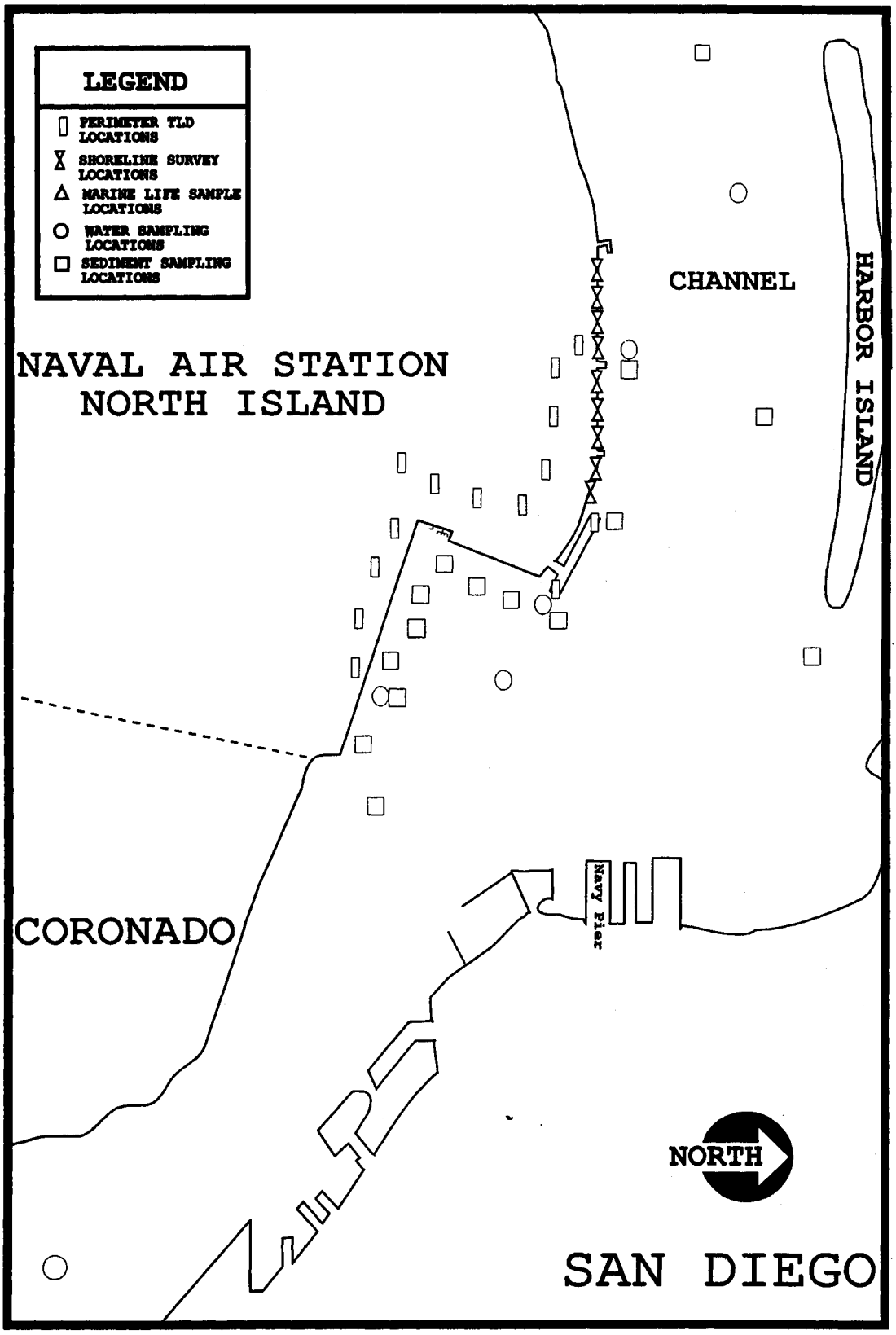


FIGURE 2
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL SUBMARINE BASE, SAN DIEGO, CA

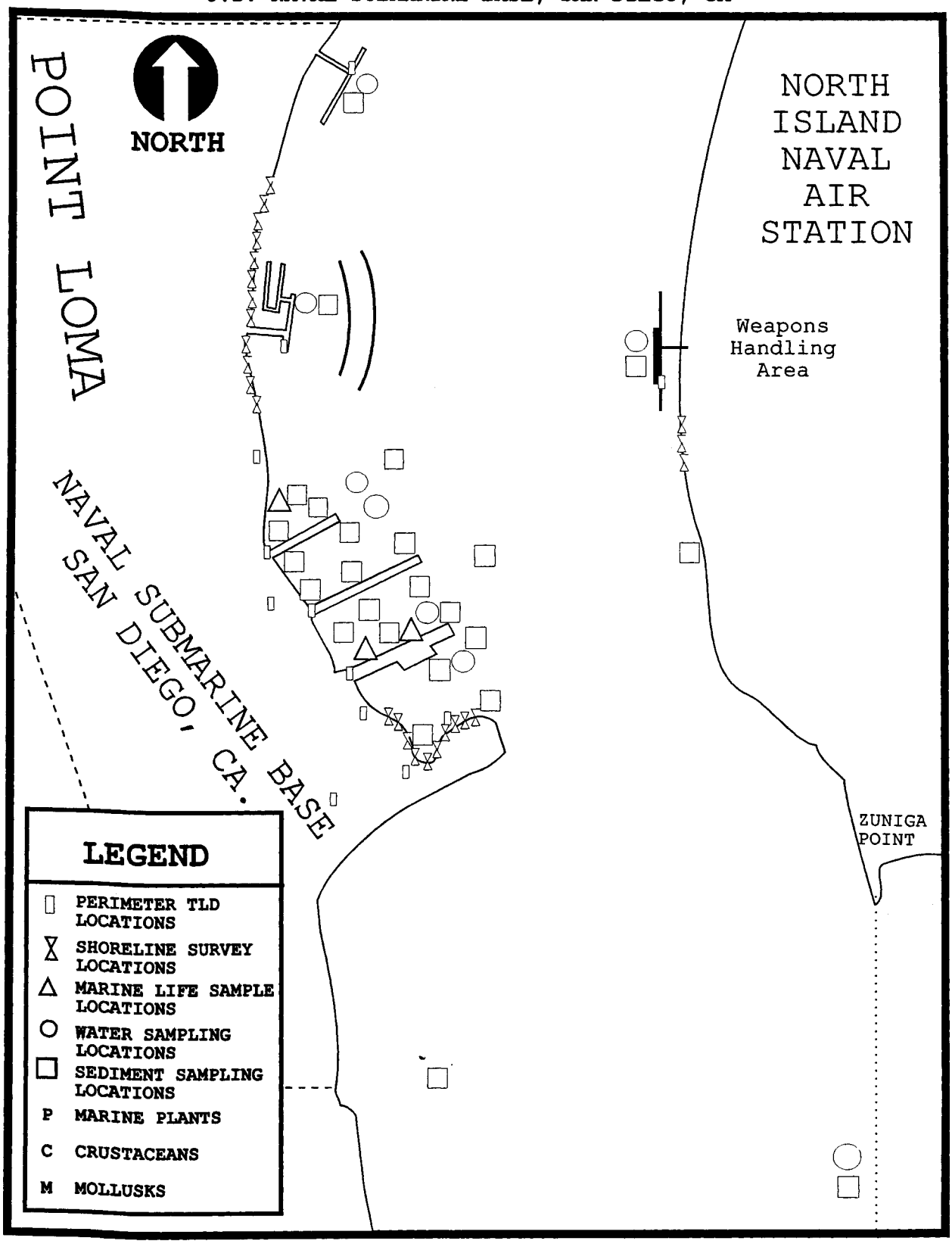


FIGURE 3
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL STATION 32ND STREET, SAN DIEGO, CA

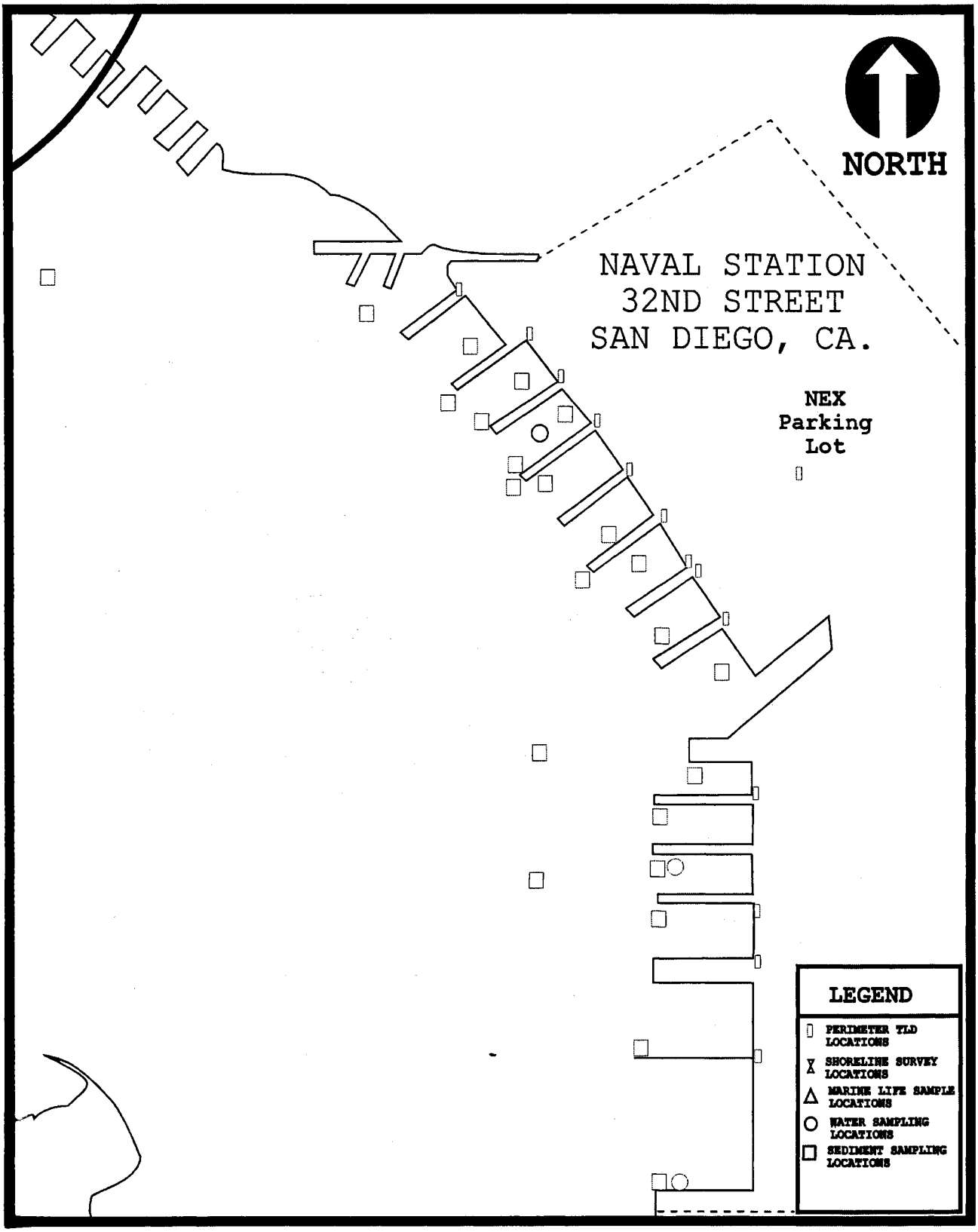
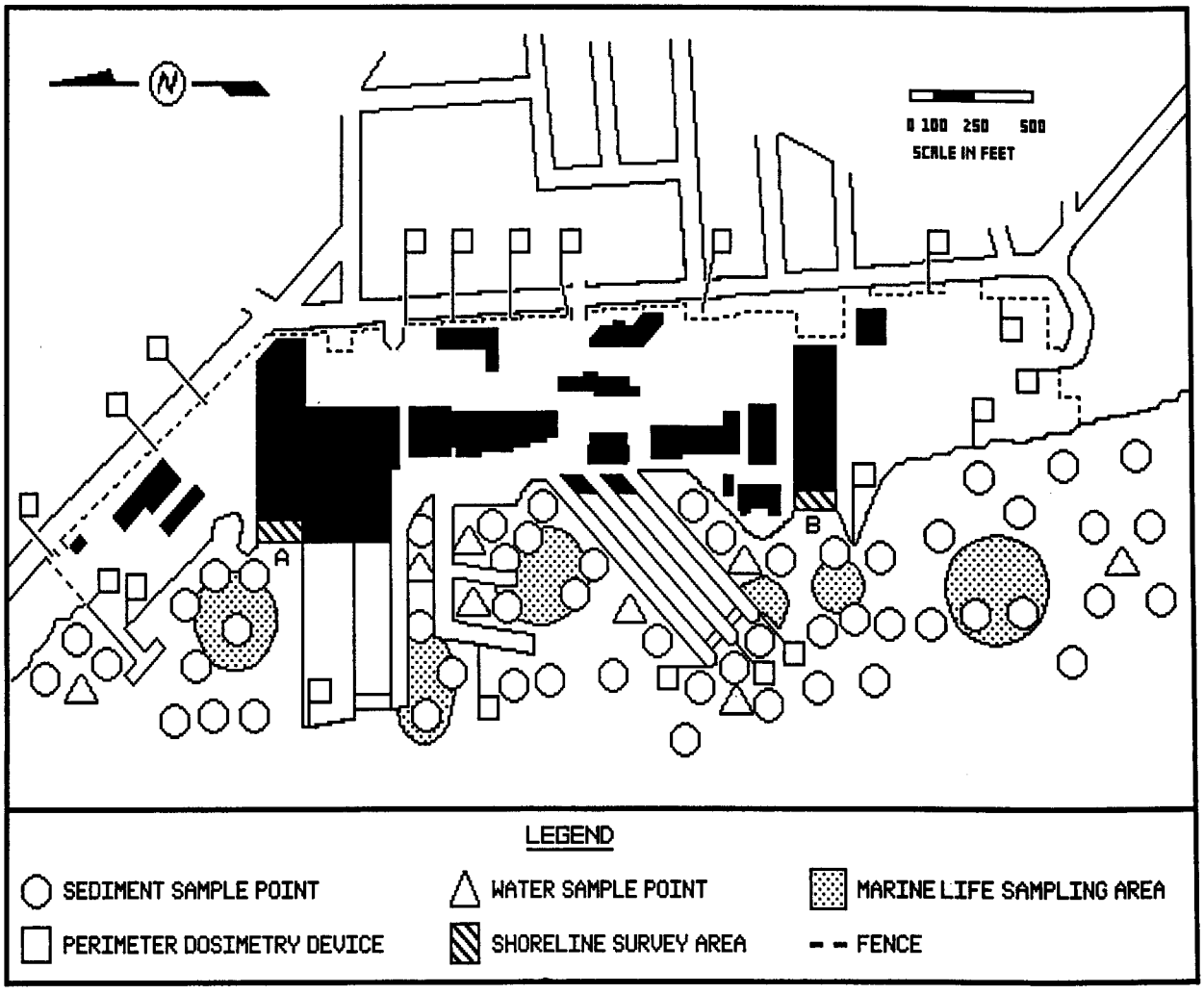


FIGURE 4
ENVIRONMENTAL MONITORING LOCATIONS AT
ELECTRIC BOAT CORPORATION SHIPYARD, GROTON, CT



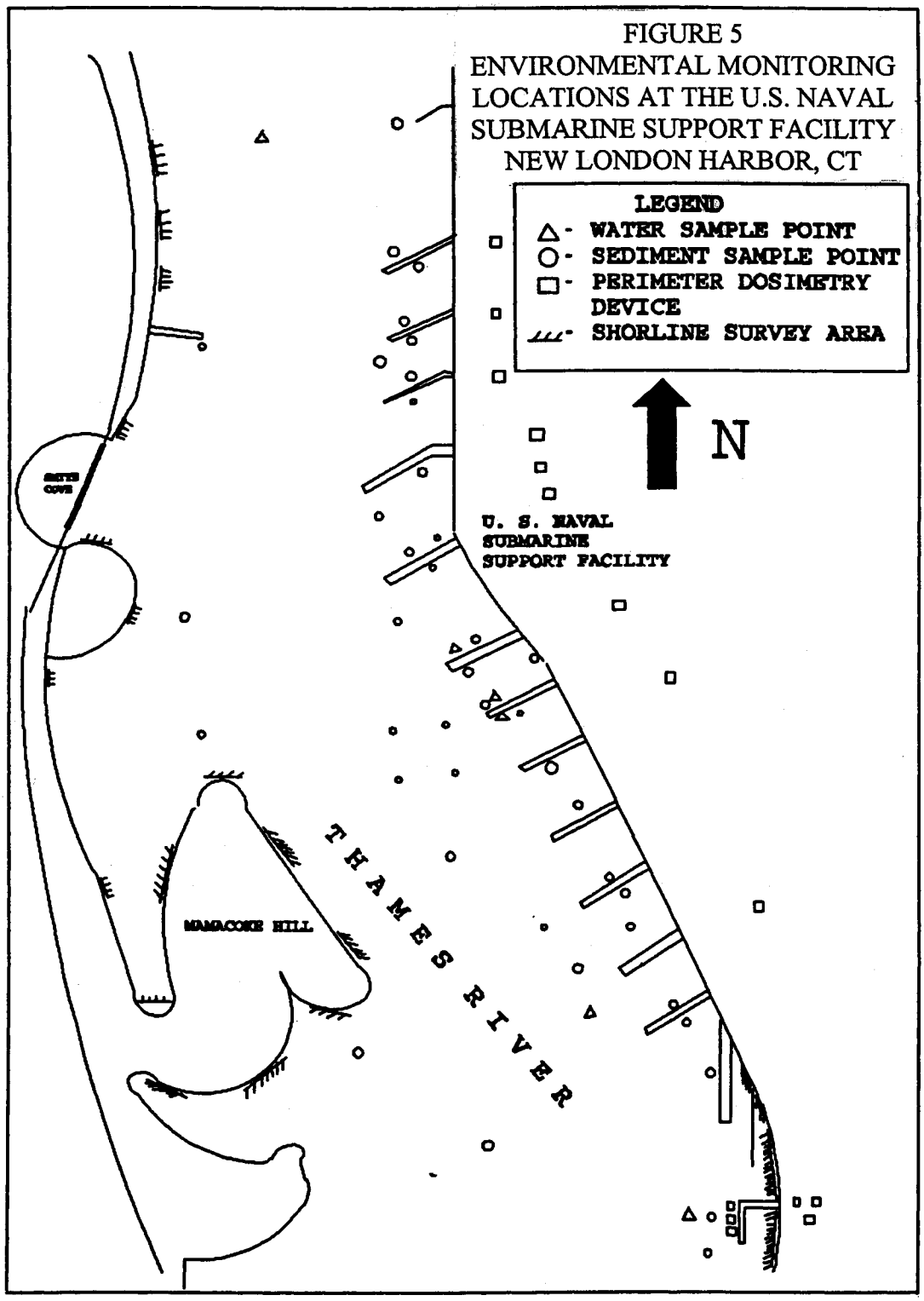
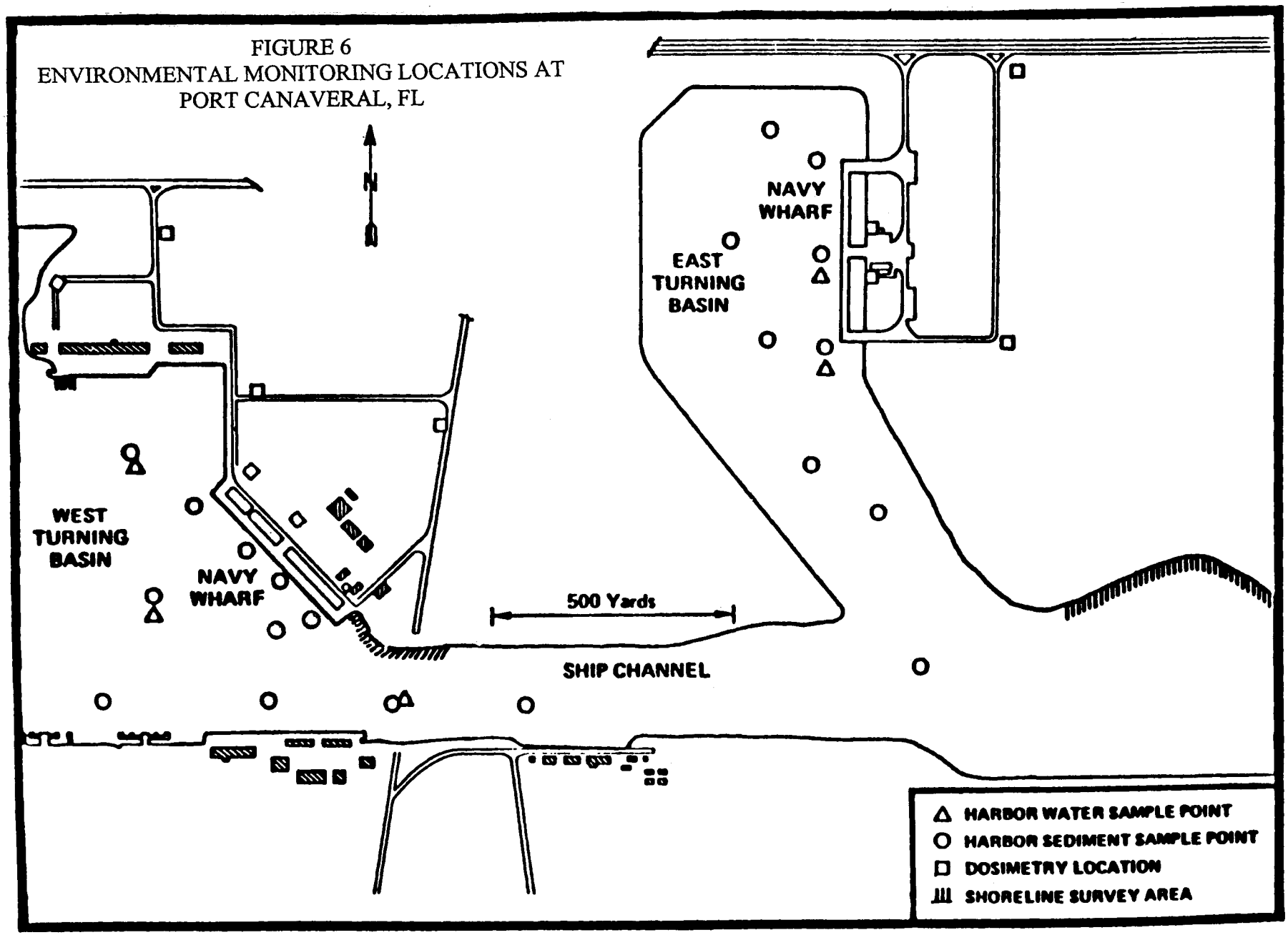


FIGURE 5
ENVIRONMENTAL MONITORING LOCATIONS AT THE U.S. NAVAL SUBMARINE SUPPORT FACILITY NEW LONDON HARBOR, CT
LEGEND
WATER SAMPLE POINT
SEDIMENT SAMPLE POINT
PERIMETER DOSIMETRY DEVICE
SHORLINE SURVEY AREA
N
U. S. NAVAL SUBMARINE SUPPORT FACILITY
MAMACOKE HILL
THAMES RIVER

FIGURE 6
ENVIRONMENTAL MONITORING LOCATIONS AT
PORT CANAVERAL, FL



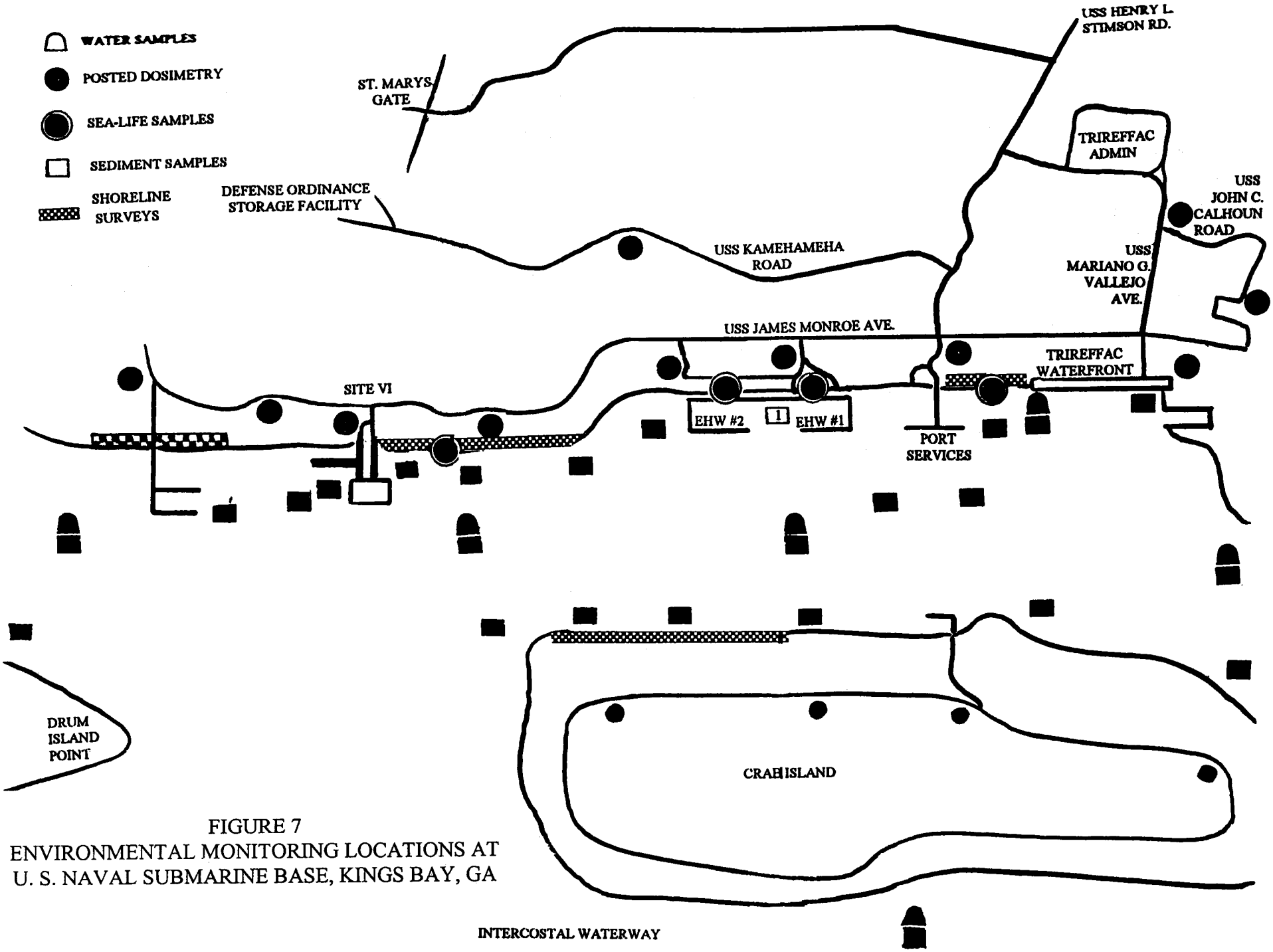


FIGURE 7
ENVIRONMENTAL MONITORING LOCATIONS AT
U. S. NAVAL SUBMARINE BASE, KINGS BAY, GA

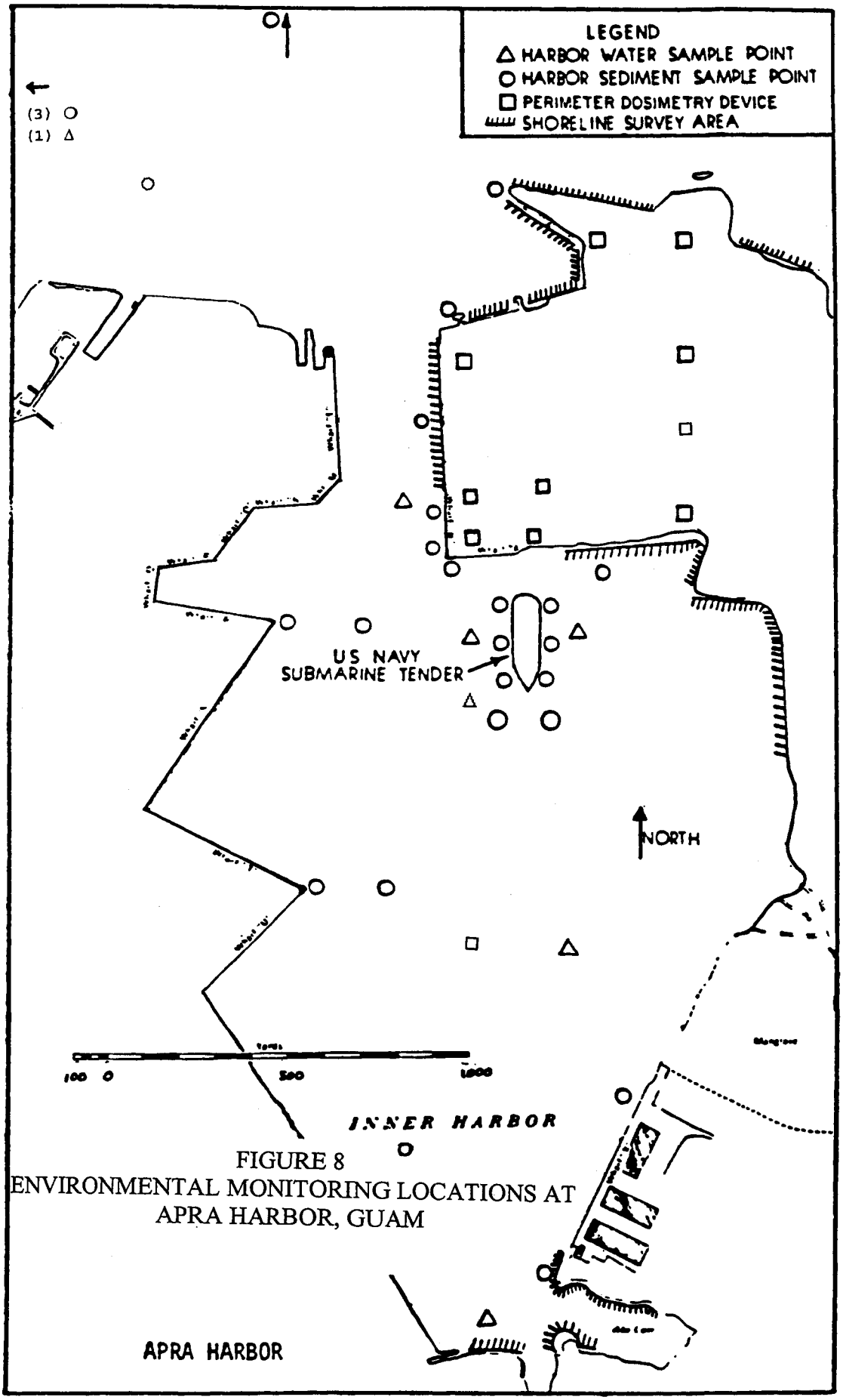


FIGURE 8
ENVIRONMENTAL MONITORING LOCATIONS AT
APRA HARBOR, GUAM

FIGURE 9
ENVIRONMENTAL MONITORING LOCATIONS AT
PEARL HARBOR, HI

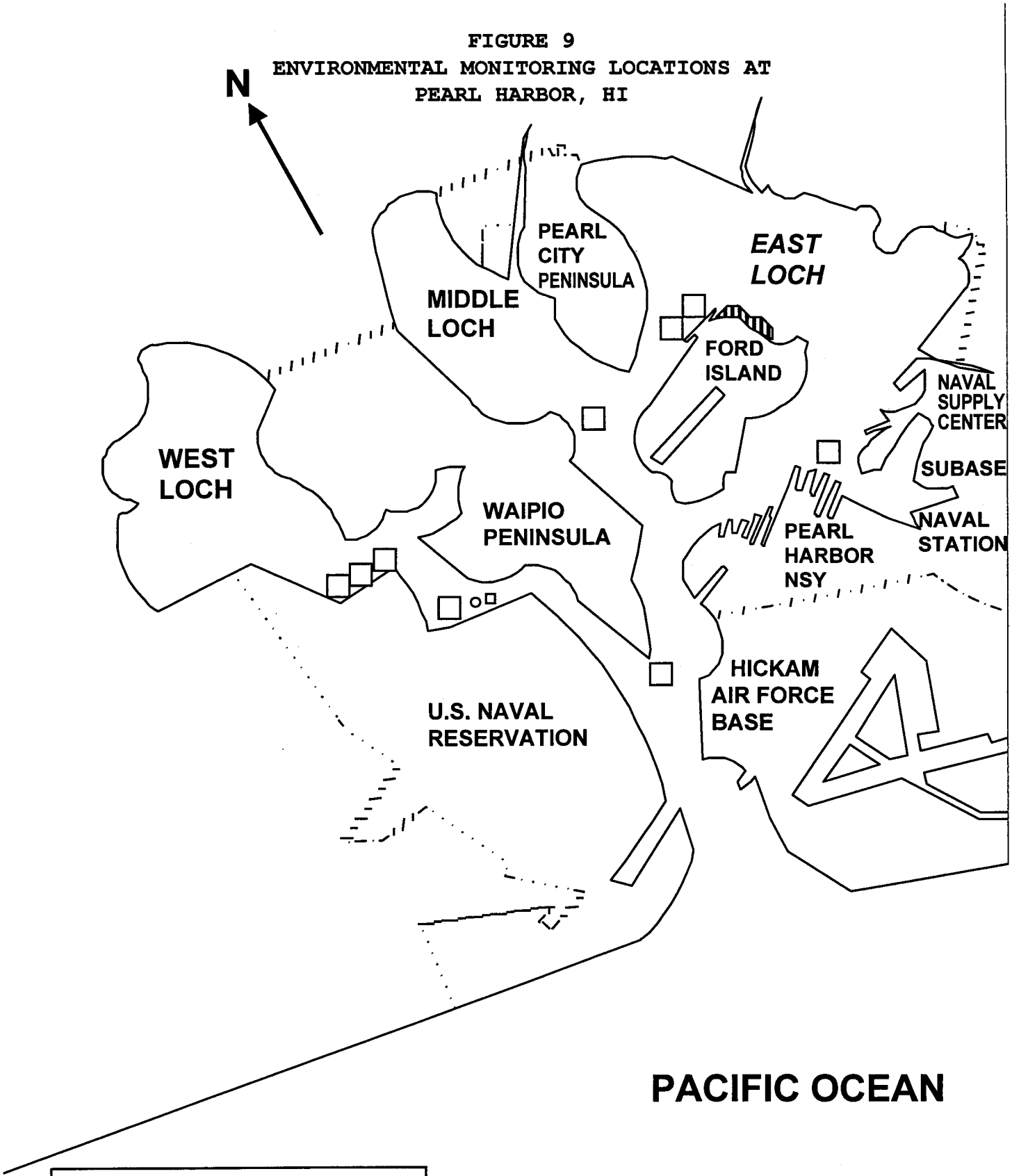


FIGURE 10
ENVIRONMENTAL MONITORING LOCATIONS AT PEARL HARBOR NAVAL SHIPYARD AND INTERMEDIATE MAINTENANCE FACILITY - SHIPYARD AREA

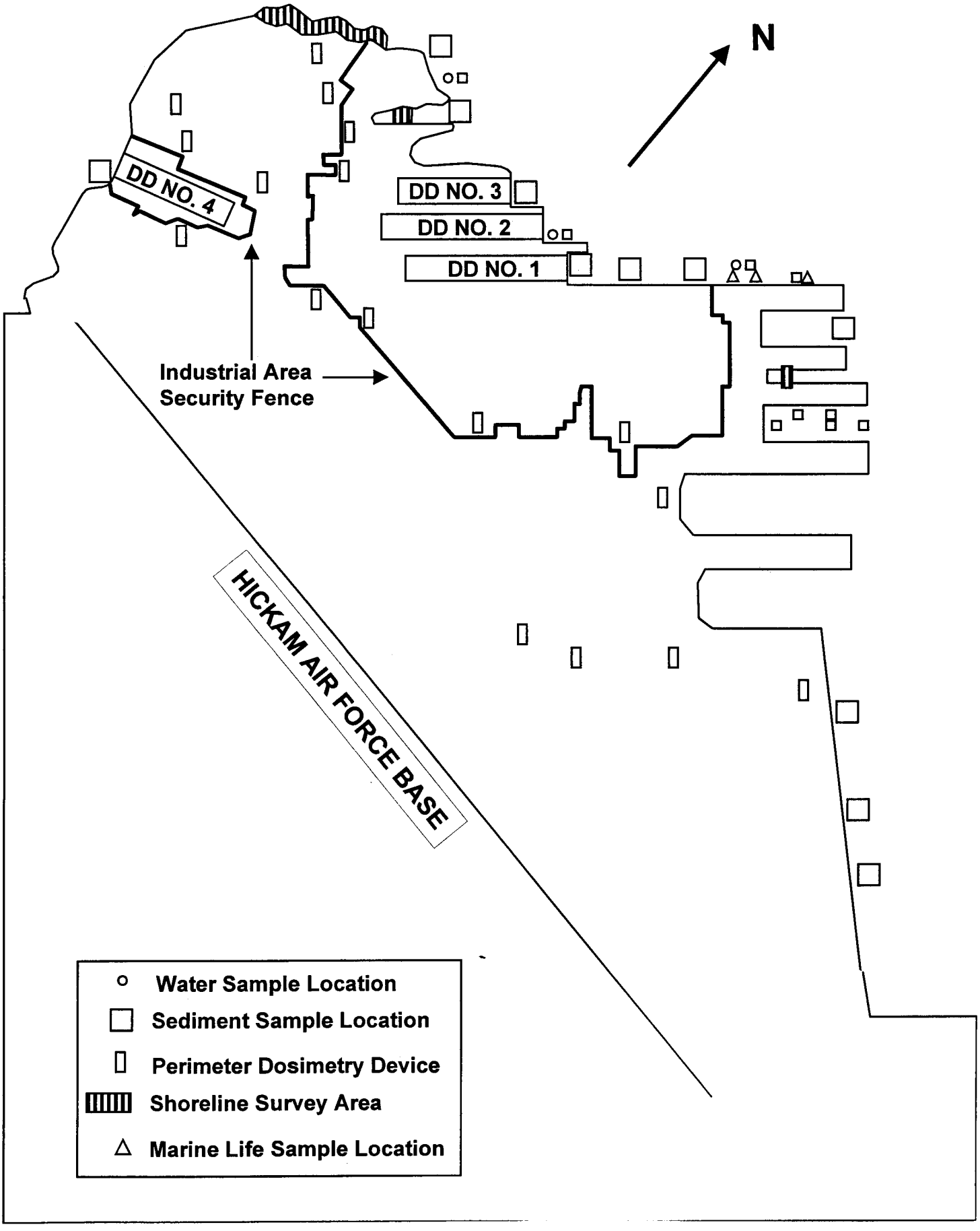


FIGURE 11
ENVIRONMENTAL MONITORING LOCATIONS AT PEARL HARBOR NAVAL SHIPYARD AND INTERMEDIATE MAINTENANCE FACILITY - SUBMARINE BASE AREA

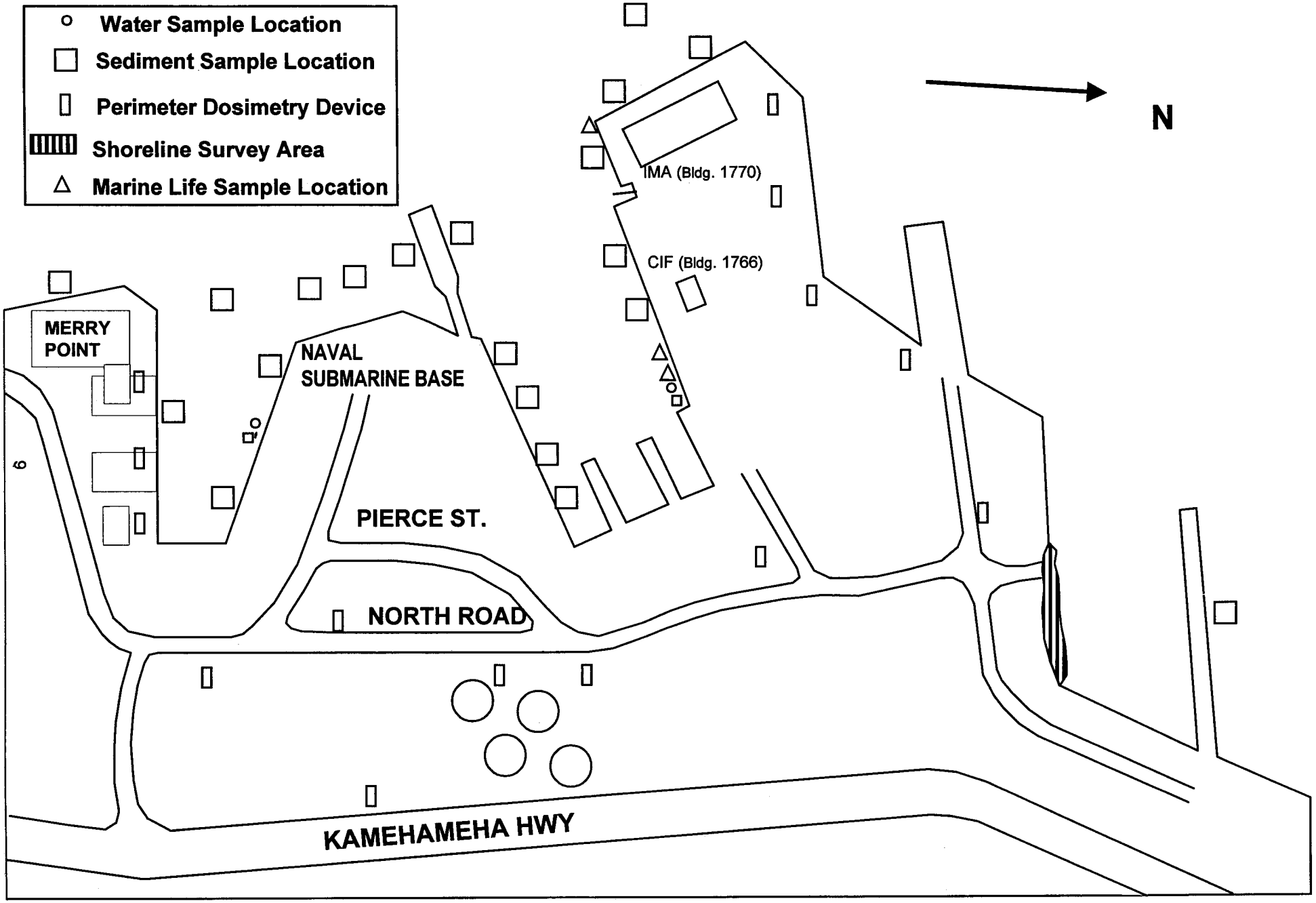


FIGURE 12
ENVIRONMENTAL MONITORING LOCATIONS AT
PORTSMOUTH NAVAL SHIPYARD
KITTERY, ME/PORTSMOUTH, NH

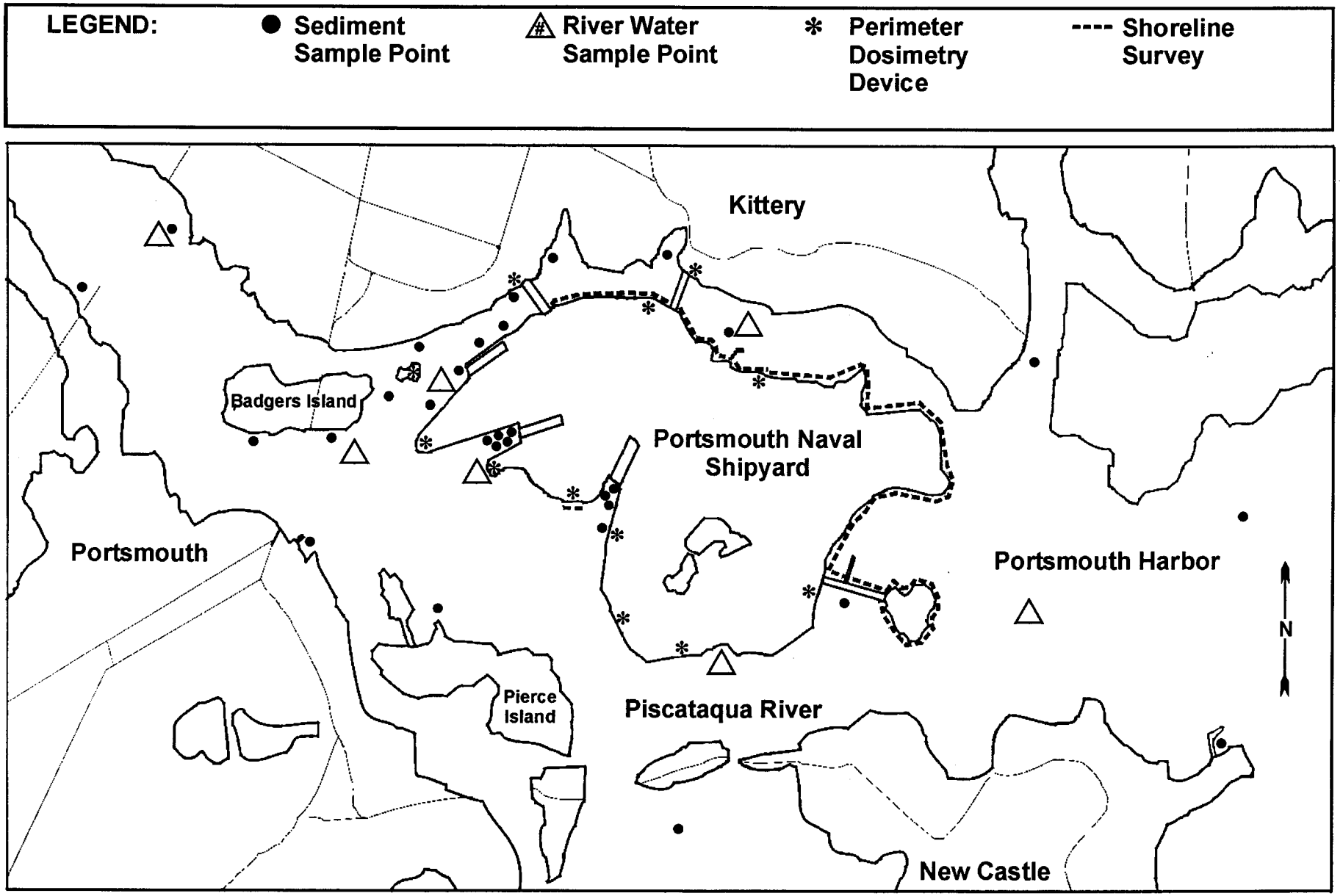


FIGURE 13
ENVIRONMENTAL MONITORING LOCATIONS AT
NAVAL NUCLEAR PROPULSION TRAINING UNIT, CHARLESTON, SC

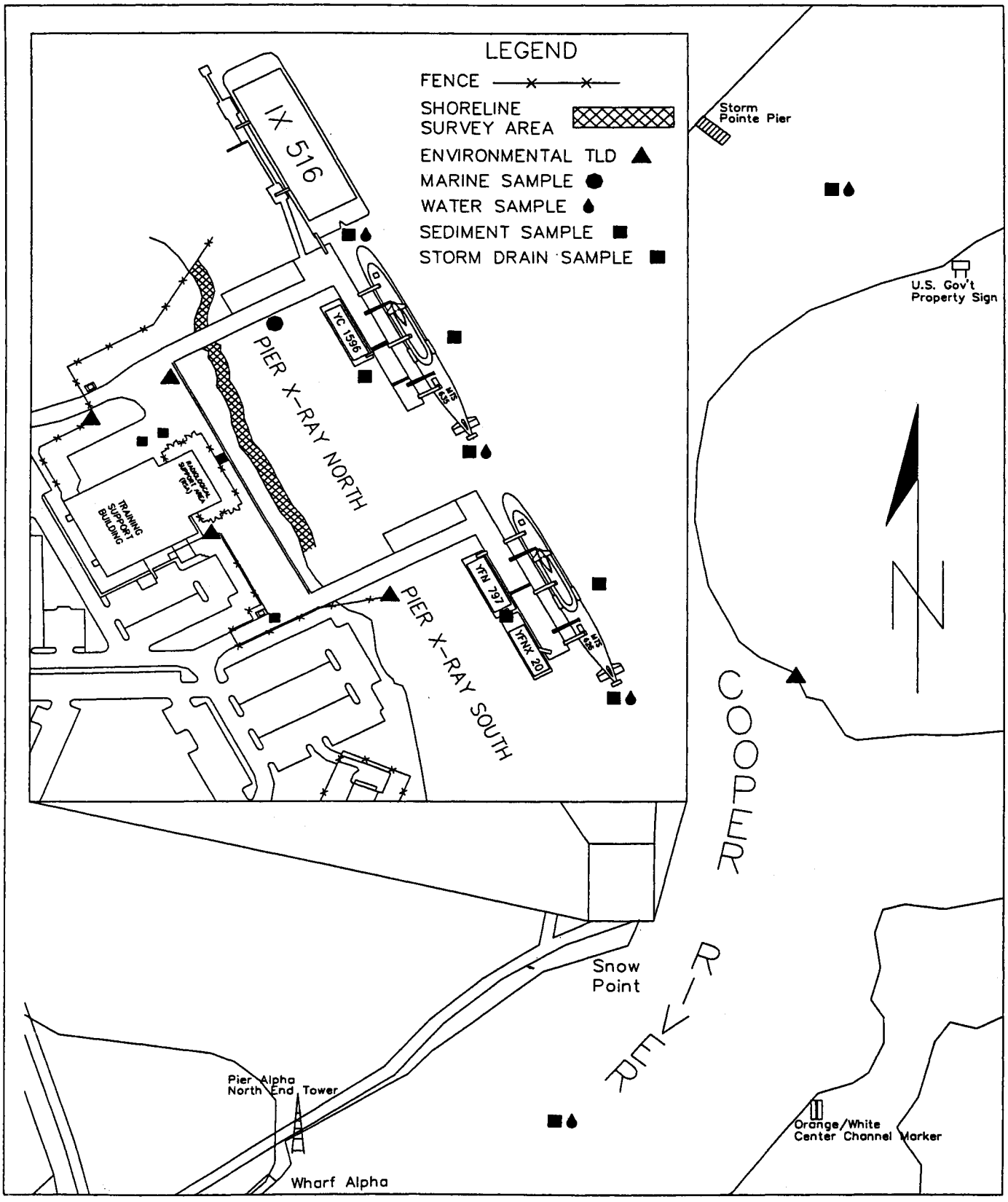
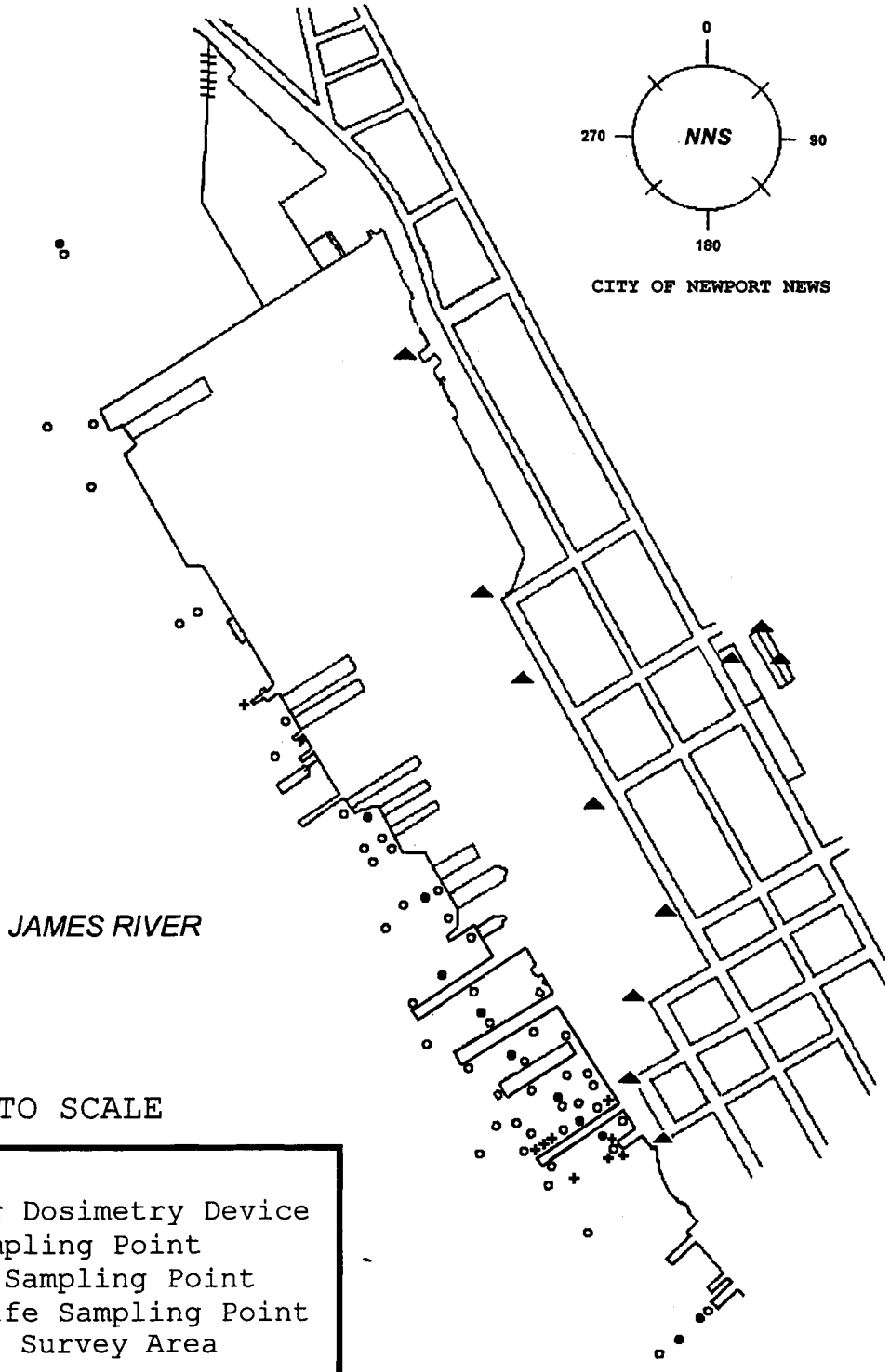


FIGURE 14
ENVIRONMENTAL MONITORING LOCATIONS AT
NEWPORT NEWS SHIPBUILDING AND DRY DOCK COMPANY, NEWPORT NEWS, VA



NOT TO SCALE

LEGEND
▲ Perimeter Dosimetry Device
● Water Sampling Point
o Sediment Sampling Point
\+ Marine Life Sampling Point
/// Shoreline Survey Area

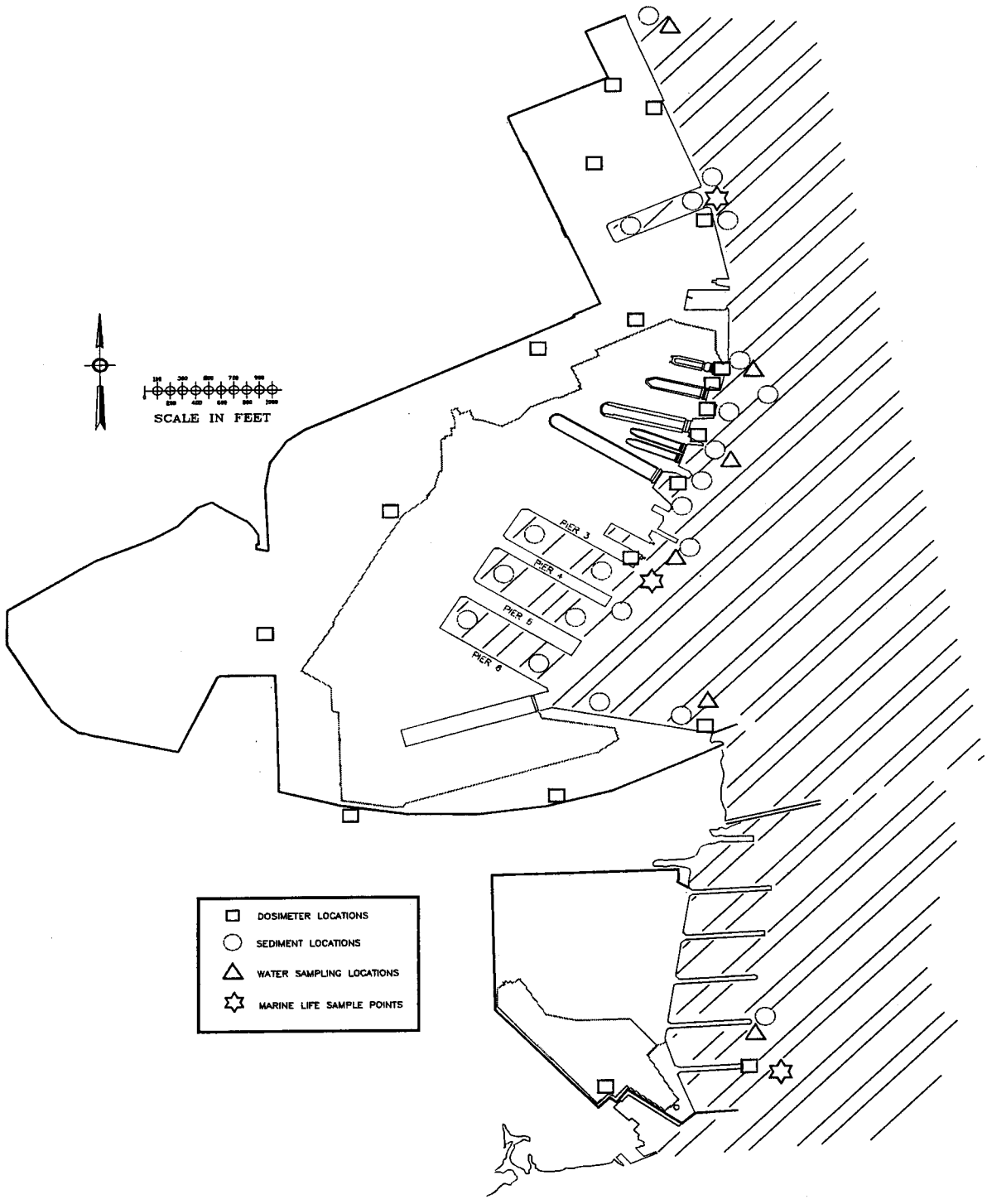


FIGURE 15
ENVIRONMENTAL MONITORING LOCATIONS AT
NORFOLK NAVAL SHIPYARD, PORTSMOUTH, VA

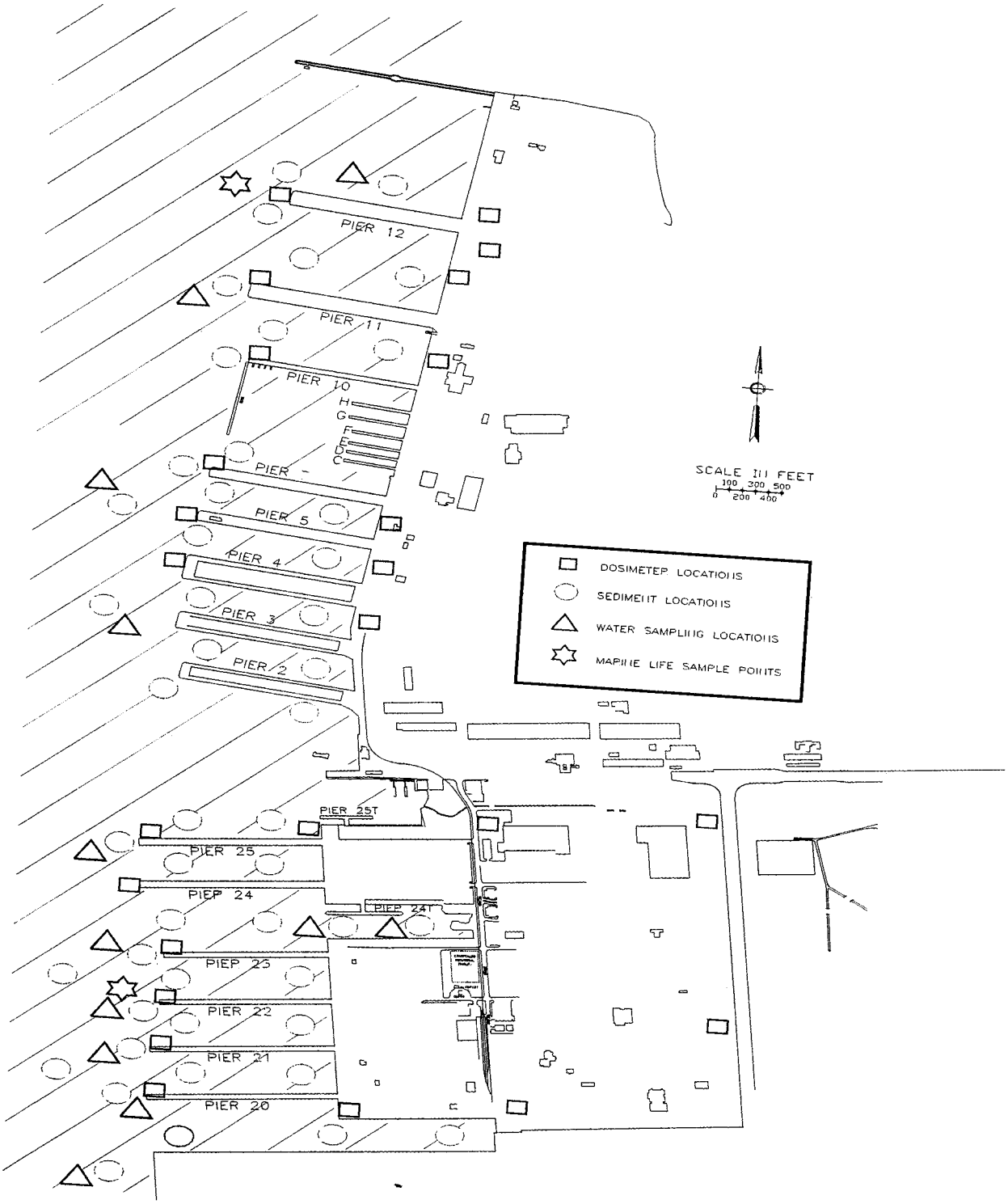


FIGURE 16
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL STATION, NORFOLK, VA

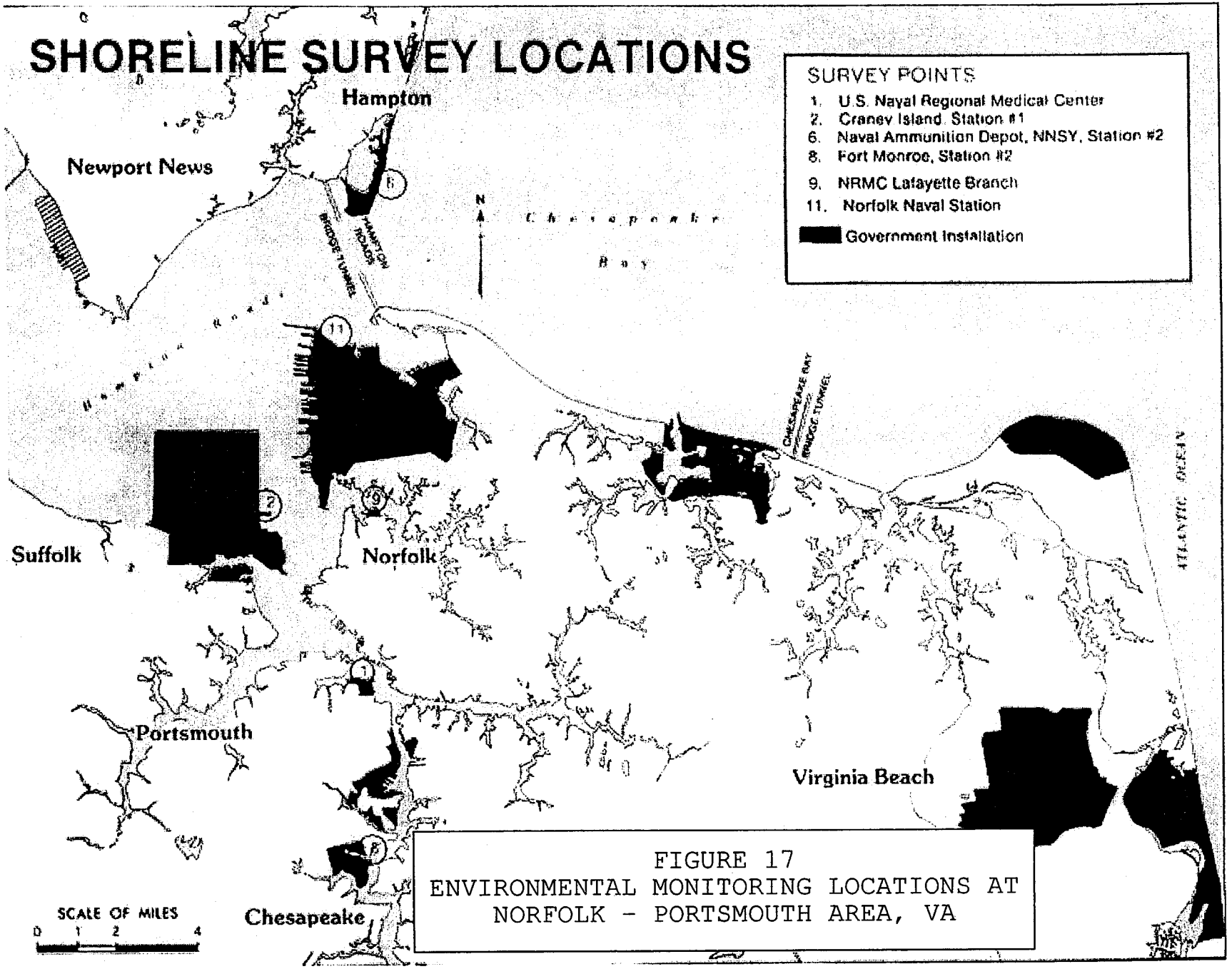


FIGURE 17
ENVIRONMENTAL MONITORING LOCATIONS AT
NORFOLK - PORTSMOUTH AREA, VA

FIGURE 18
ENVIRONMENTAL MONITORING LOCATIONS AT
PUGET SOUND NAVAL SHIPYARD, BREMERTON, WA

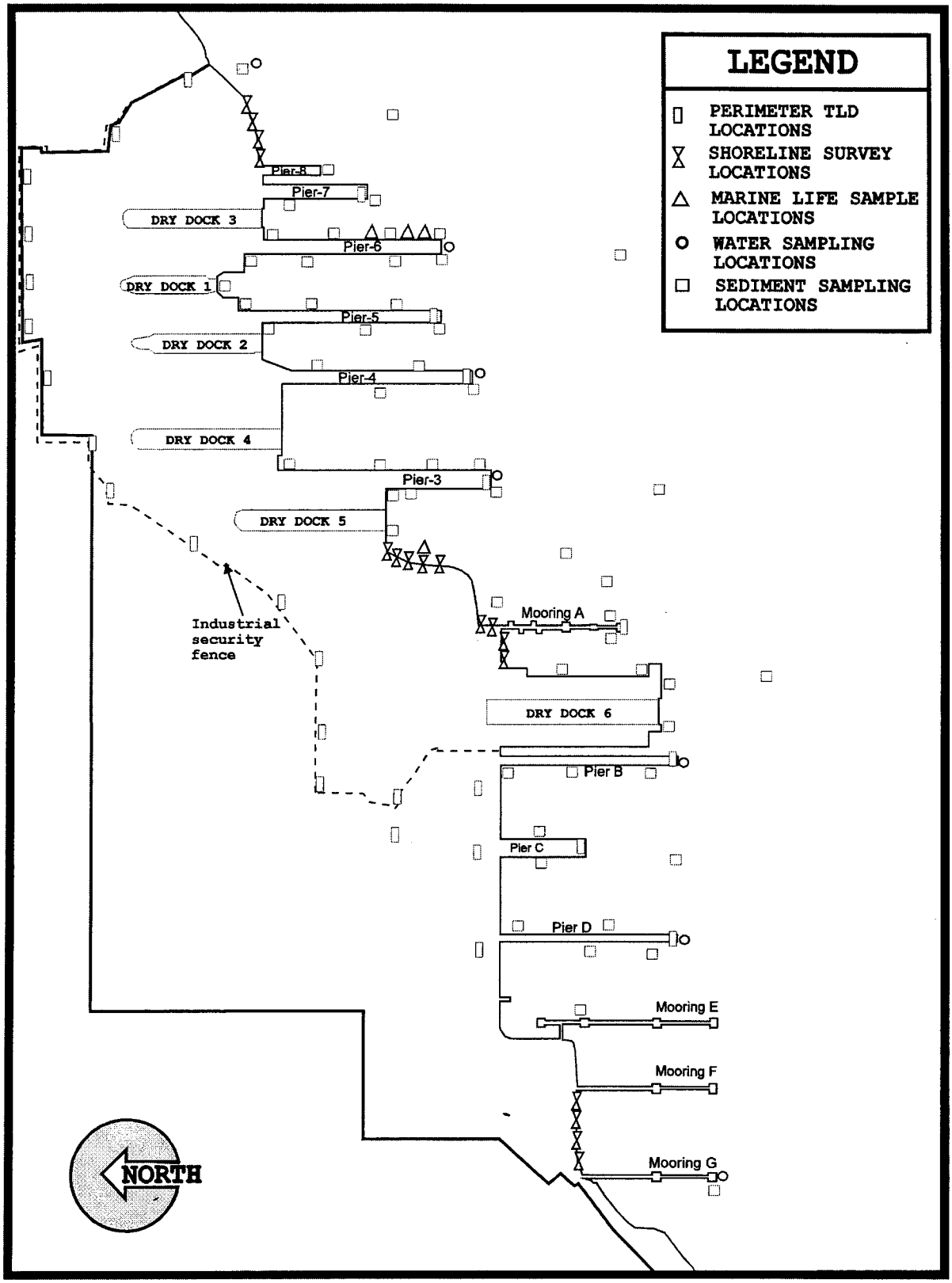


FIGURE 19
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL SUBMARINE BASE, BANGOR, WA

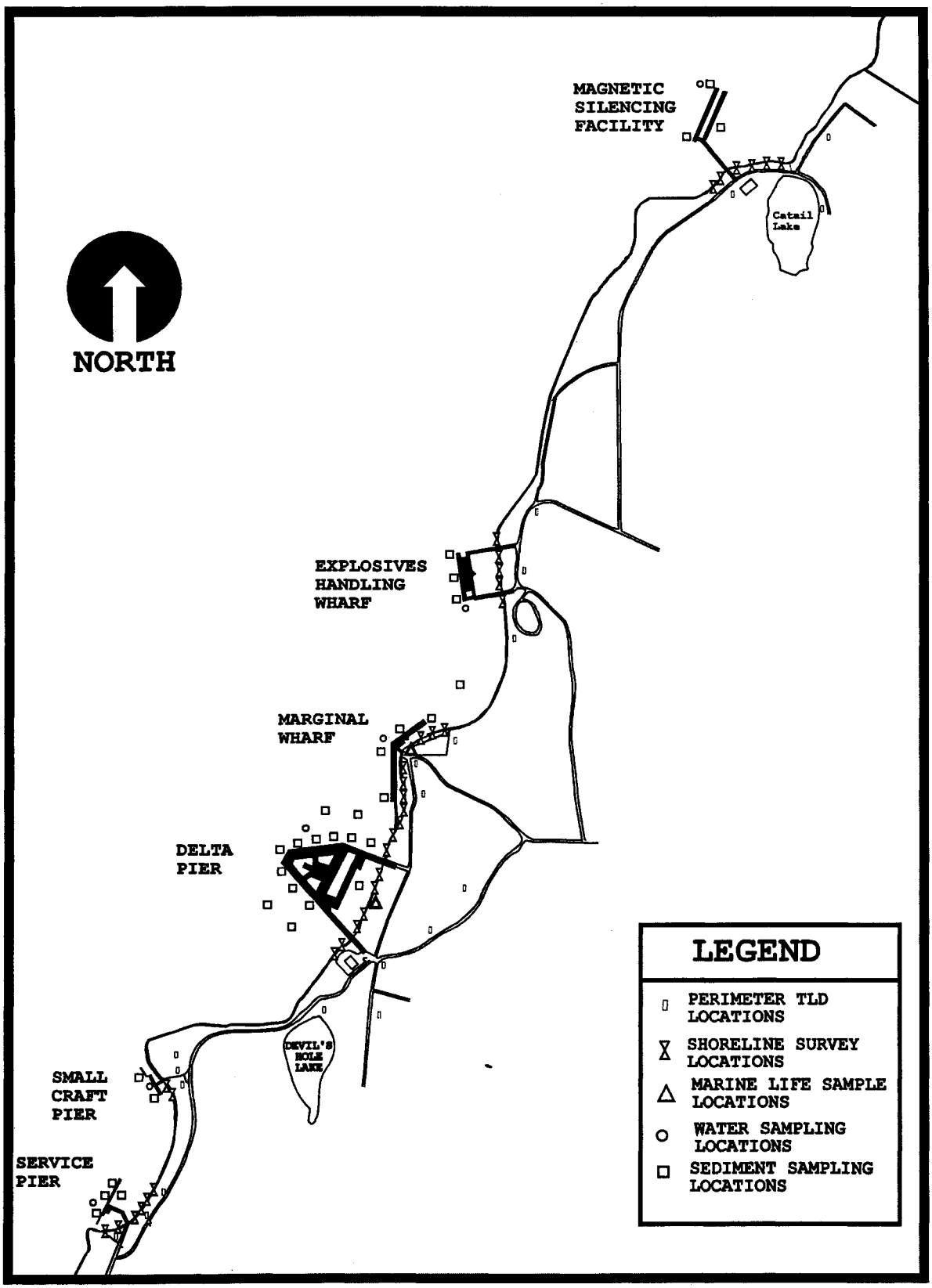


FIGURE 20
ENVIRONMENTAL MONITORING LOCATIONS AT
U.S. NAVAL STATION, EVERETT, WA